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LASSEN PEAK—OUR MOST ACTIVE VOLCANO[1]

By J. S. DILLER

Note.—Articles on the recent activity of Lassen Peak have been published by J. S. Diller in this BULLETIN, September 1914; by R. S. Holway in University of California Publications in Geography, August 7, 1914; *Popular Science Monthly,* March 1915; and *Sunset,* August 1915; and J. W. Rushing in *The Dam,* July and September 1915.

The physics and chemistry of the recent eruptions of Lassen Peak are being investigated by Drs. A. L. Day and E. S. Shepherd of the Geophysical Laboratory, Washington, D. C.

Lassen Peak, our most active volcano, lies in the northeast portion of California, about 210 miles from San Francisco. It is the terminal peak at the southern end of the Cascade Range, and stands between the northern end of the Sierra Nevada and the Klamath Mountains. It is on the edge of one of the greatest lava fields in the world, extending from northern California, Oregon and Washington eastward across Idaho into Wyoming, covering an area of about 250,000 square miles. Over the eastern portion of this field most of the lava is basalt which was very liquid at the time of its eruption and spreading far and wide like water it formed a flattish country, the Columbia plateau, but along the western border of the lava it is chiefly andesite, a viscous lava that did not spread when it was erupted but piled up about the vents from which it issued and built up a mountain range, the Cascade Range, surmounted by great peaks, from Lassen Peak, which rises 10,460 feet, to Mount Rainier, that attains an elevation of 14,408 feet.

Are these great volcanoes extinct? is a question that is frequently asked; and in answering, Not wholly extinct,—one needs but call attention to the fact that in 1843, about the time Fremont crossed the continent, Mount Baker and St. Helens were both active, spreading ash far and wide and killing the fish in some of the rivers. A sample of the material was collected for Fremont at the Dalles of

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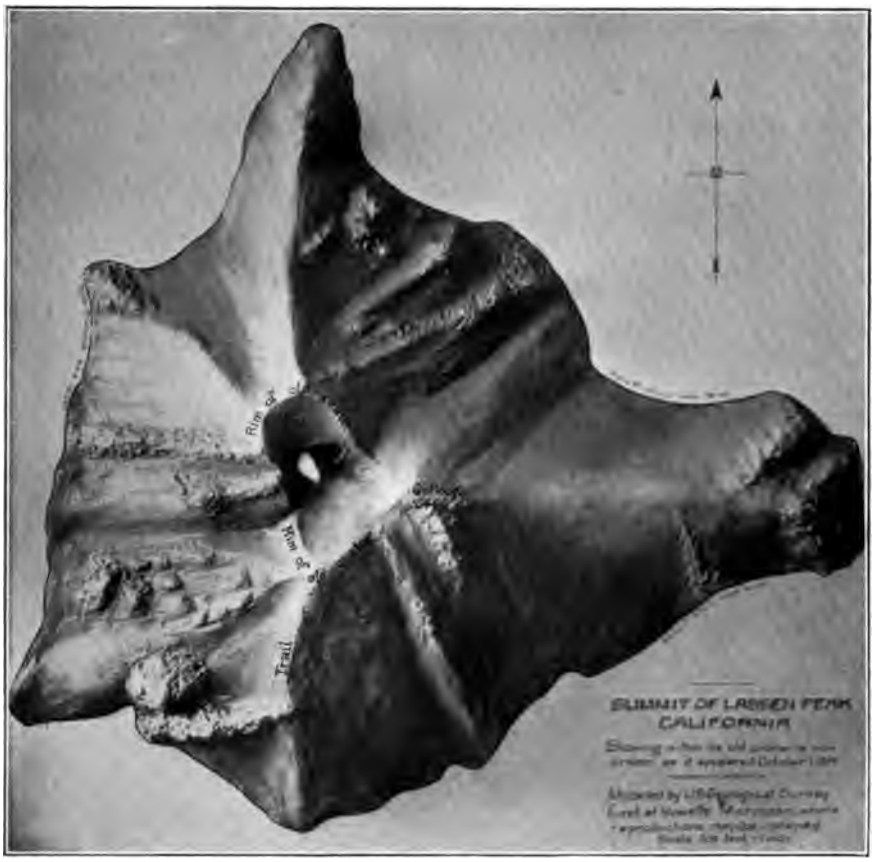

Fig. 1. Summit of Lassen Peak, California, above the 9,500-foot contour, as seen from above, showing the summit spurs radiating from the rim of the old crater, within which the new crater, as it appeared October 1, 1914, contains a jet of steam.

The new crater elongated and widened by successive eruptions until about the end of March, 1915, when it occupied by far the greater portion of the old crater, and then the bottom began to upheave.

Modeled by the U. S. Geol. Survey. Cast at Howell's Microcosm, Washington, D. C., where reproductions may be obtained.

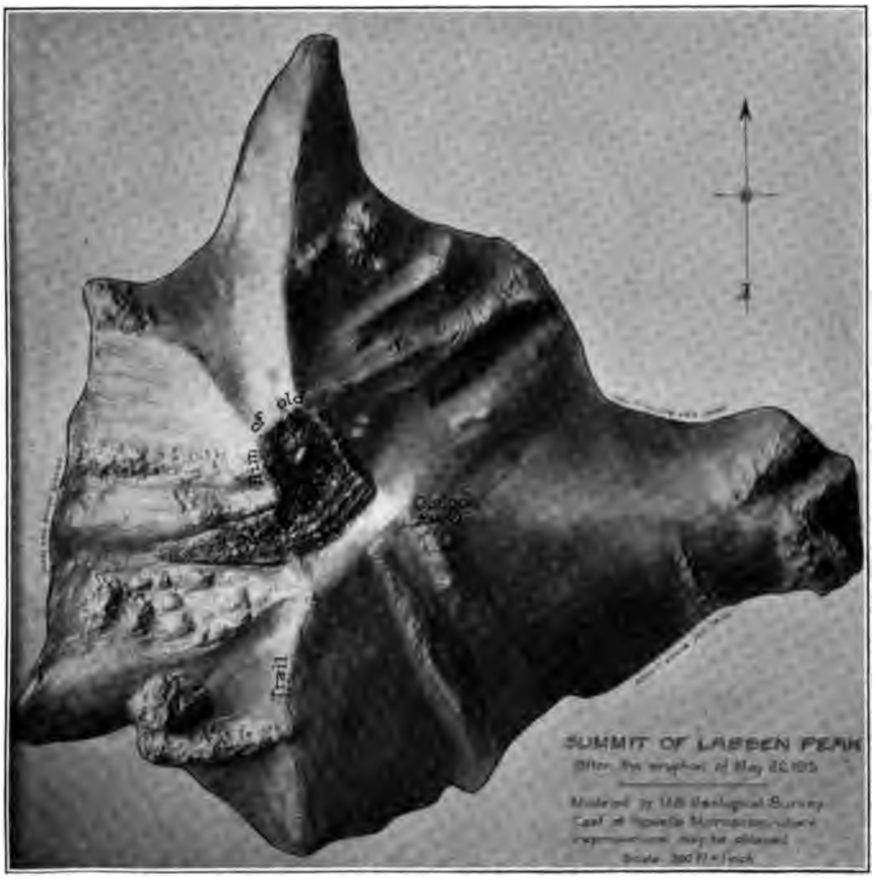
Rim of old
Trail
SUMMIT OF LASSEN PEAK
after the eruption of May 22, 1915
Modeled by U.S. Geological Survey
Scale 300 ft = 1 inch

Fig. 2.

The upheaval of the bottom within the new crater began probably about April 1, 1915, and continuing through April and early May culminated in the great eruption of May 22, 1915, which resulted in the extrusion of a mass of new lava, so that it filled both the new and old craters to the rim as a "lid," and, overflowing through the notch, the new lava extended a short distance down the west slope. The hot blast that devastated the Hat Creek country escaped from beneath the edge of the lava lid at the head of Lost Creek.

Jets of steam are shown on the northeast slope. The jets of steam from the northwest fissure and on the west slope are not clearly visible in the high light.

mountain to see the new crater. But occasionally they were unfortunate. June 14, 1914, after there had been ten eruptions, a party of ten men ascended the mountain and were looking down into the new crater when a great eruption began. Without previous warning a great volume of steam rushed up with a roar as of many engines, carrying forth rock fragments and dust. The people ran for their lives, seeking shelter behind rocks. They were soon enveloped by the cloud of vapor and complete darkness, and remained so for more than ten minutes. Some buried their faces in the snow to escape breathing the dust. One was hit by a falling rock and badly injured, but none were killed. The experience of this party is interesting in demonstrating that in the early stages of the volcano the gases were neither so hot nor so acid as to destroy life.

More than 150 eruptions occurred during the first year, and a number of them had an energy so great as to hurl a column of smoke to a height of more than 10,000 feet. Each eruption enlarged the new crater. First its length was increased along one set of joint fractures to the westward; but later it widened along another set until it attained a size of about 700 x 1,000 feet and occupied the greater portion of the old crater. The ejected material as it fell about the crater rim became stratified, and accumulated to the thickness of nearly 50 feet. A few stones were thrown as much as a mile from the crater. The largest stone thrown out dropped on the crater rim. It has a diamenter of about 15 feet, and weighs over 60 tons. Two miles from the crater scarcely a trace of dust can be seen except to the northeast, the direction in which it has been carried many miles by the prevailing winds.

The second phase of the volcanic activity of Lassen Peak included the eruption of lava which culminated in the great outbreaks of May 19 and 22, 1915.

The gas eruptions of the first phase had cleaned out the old crater of Lassen Peak, opening the volcanic chimney to about its full size. The hot magma, more or less viscous in the lower portion of the chimney or throat of the volcano, was forced upward by pressure of magma or gas from beneath, and was gradually upheaved, perhaps during the greater part of two months, April and May, 1915, until it reached the surface as new lava and filled not only the new but also the old crater, so as to form a "lid" on the volcano.

March 23d, Mr. E. N. Hampton ascended Lassen Peak and took the last photograph that will ever be taken of the new crater within the old one, for from that time to May 22d, when the great eruption occurred, no one ascended the mountain to see what was going on.

Eruptions continued most of the time during the interval of two months, and a great change was wrought. The first to notice from a distance a change of form on the summit was Mr. B. F. Loomis, after the eruption of April 9th. A black edge of lava appeared in the notch at the northwest corner of the old crater rim.

On the evening of May 14th fire was reported on the summit as seen by Miss Dines and a number of others from Manton. The alarm was spread by telephone and many saw the glow from the Sacramento Valley, as well as from the southeast of the mountain at Chester, where G. W. Olsen was observing.

The activity continued, and on the night of May 19th was even more conspicuous. May 20th J. R. Milford wired the Geological Survey, "Lassen Peak in violent eruption 9:30 to 11:30 last night. Fire observed coming from crater. Incandescent ejecta roll down the mountain side. I observed the spectacle from Viola, ten miles from Lassen Peak. Many in Sacramento Valley saw the same."

The ejection at night of luminous fragments flying through the air, and flashes of light with glowing clouds over the crater, reminding one of Stromboli, the lighthouse of the Mediterranean, have been observed a number of times by so many persons on all sides of Lassen Peak that they furnish evidence that some of the material ejected from Lassen Peak recently has had a temperature sufficiently high to render it luminous, that is, a temperature probably between 600° and 900° C. A temperature so high must have a marked effect in diminishing the viscosity of the magma in the neck of the volcano, and make it more easy to upheave to the surface to form the lava lid and the little flow of new lava on the west slope. As the lava reached the surface it was chilled and fractured. Several fault fissures traversed the mass nearly east and west, parallel to the length of the new crater. Irregular vertical rifts are common transverse to the line of motion, as in glacial ice. The fragments in the lava lid were shoved about somewhat, and yet there are large masses that show a good degree of continuity, reminding one of similar masses in the lava field of the Cinder Cone, ten miles northeast of Lassen Peak, where the lava mass was entirely molten at the time of its eruption.

Although the extrusion of the new lava and the formation of the lava lid was the main feature of the great eruptions in May, it was by no means the most astonishing and destructive.

On the night of May 19th it appears that the superheated gases which accumulated beneath the lid forced up the lid and escaped with terrific force down the deep snow-covered northeast slope of Lassen Peak toward Lost Creek and Hat Creek. The snow was instantly converted into water, and the mighty onrush of water and blast of hot gases swept everything before it for more than ten miles along Lost Creek, forming a devastated belt from a few hundred yards to a mile in width. Meadows were buried beneath finer debris and occasional large boulders broken off from the edge of the lava lid far above. Trees three feet in diameter were broken off or uprooted, and the country scoured as by a mighty sand-blast. The fine green leaves of the pine trees left standing along the borders of the blast were killed by the heat and turned brown. Locally, on favorable slopes, the heat was so great that the green leaves were charred: not only those of the pine but also those of the manzanita, several acres of which, at a distance, had the general appearance of an area swept by a forest fire. In fact it is stated by Mr. Seaborn of the Forest Service, who was in that region at the time, that two fires were actually kindled by the eruption.

This reminds one of the hot blast from Mount Pelée that destroyed St. Pierre. Luckily in the Hat Creek region there were only a few summer residents. Warned by the noise of the approaching torrent they escaped to the hills.

That no one was killed was simply a matter of good fortune on the part of the eleven enthusiasts who early visited the region to make a photographic record. Mr. B. F. Loomis, the veteran photographer of Viola, was among them.

There were two devastating hot blast eruptions into the Hat Creek country, one on the night of May 19th and the other on the afternoon of May 22d.

The Loomis party arrived on the scene about noon May 22d and spent several hours photographing up to the head of Lost Creek. They left soon after three o'clock, and had scarcely reached the Manzanita Lake side of the mountain when the most violent eruption occurred, sending its column of smoke to a height of 30,000 feet and a hot blast down into the Hat Creek country that would probably have killed the whole party had the eruption occurred a few hours earlier.

Among the fragments ejected by the later eruptions there are numerous volcanic bombs, having the peculiar cracked surface characterized as bread-crust structure. Of all the products of recent eruptions at Lassen Peak these furnish the most impressive evidence that the lava at the time of eruption was partially fused—that is, somewhat softened by heat. They are generally composed of very porous lava or flow breccia, in which there is a fluxion structure perpendicular to the bread-crust surface.

The general view as to the origin of the bread-crust surface is that it is produced by the expansion of the bomb beneath the crust so as to crack its surface.

At the time of the great outbreak a fissure was opened running from the summit northwest about 1,000 feet down the slope toward Chaos Crags. Three vents were opened at this fissure, and the greater portion of the volcanic activity since the great eruption of May 22d has been confined to this fissure, which was active throughout the summer of 1915.

October 19, 1915, G. W. Olsen examined the summit and found no steam rising from the northwest fissure. A new fissure had formed about 400 feet farther east on the rim, and the late eruptions have occurred chiefly from the new fissure.

On December 31, 1915, Lassen Peak completed nineteen months of volcanic activity; and in that time, according to the list prepared from various sources and to be published later, there were 220 eruptions, of which 143 occurred in the day time after 7 a.m. and 77 at night after 7 p.m. It is possible that there were many other small eruptions at night unobserved. The larger eruptions at night, as on May 19th and 22d, as well as October 30, 1914, manifested themselves by flashes of light, flying red-hot bombs shot high in the air, and a distinct glow of the clouds over the crater reflecting the light from the incandescent lava beneath; but even such features may escape notice or report in a sparsely populated region.

The eruptions began May 30, 1914, and during the succeeding months and seasons the numbers of eruptions were as follows:

1914,	Summer,	38	(June, 15; July, 14; and August, 9)
"	Autumn,	56	(Sept., 21; Oct., 20; and Nov., 15)
1915,	Winter,	40	(1914, Dec., 15; Jan., 18; and Feb., 7)
"	Spring,	44	(March, 14; April, 13; and May, 17)
"	Summer,	17	(June, 8; July, 5; and August, 4)
"	Autumn,	22	(Sept., 8; Oct., 10; and Nov., 4)
1916,	Winter,		(1915, Dec., 2; Jan., 0;)

Dividing the twelve-hour day from 7 a.m. into three equal portions—morning, noon, and evening—of four hours each, it is found that while 57 eruptions occurred in the morning, 40 occurred at noon and 46 in the evening. The variation is very irregular from month to month, and it does not seem at all probable that one time of day is more favorable for eruption than another. It has been supposed that a greater supply of surface water might favor eruption. If that be true, we would expect more frequent eruptions in the late afternoon or early evening, when the day's supply of water from melting snow is at its maximum. On the contrary, the mornings have most eruptions, at a time when the daily heat and water supply are near their minima.

That the volcanic energy is not dependent upon the supply of surface water to form steam is suggested by the fact that summer and autumn—the dry season—with least water, have a greater number (94) of eruptions than (84) the wet season of winter and spring.

If we compare the number of corresponding seasonal eruptions in 1914 and 1915 the result appears significant. In the summer of 1914 there were 38 eruptions, but in 1915 only 17. In the autumn of 1914 there were 56 eruptions, while in 1915 there were only 22. Since the great eruption of May 22, 1915, when the new lava was extruded and the lava lid formed, the number of eruptions has decreased, and the decadence continues; but whether or not the active period of Lassen Peak is approaching its close, although probable, may be more certainly told next summer.

With its comfortably active volcano, inviting cinder cones and lava fields, glaciated divides and canyons, vigorously boiling hot springs, mud lakes and "mush pots" in a setting of lovely scenery and attractive camps, easily accessible, the Lassen Peak region affords one of the most alluring and instructive spots for a national park.

U. S. Geological Survey, Washington, D. C.
February 25, 1916.

CALIFORNIA EARTHQUAKES DURING 1915

By ANDREW H. PALMER, Observer, U. S. Weather Bureau

Of the many tributes paid to California during the past year none is more appropriate and more worthy of repetition than the following:[1] ". . . . no other state is so crowded with scientific interest. In the presence of living volcanoes, living glaciers, and great recent earthquakes one finds geologic history still being written. The state is absolutely unique also in many of the features of its present abounding animal and vegetable life, especially perhaps in its forest and desert floras, and is no less unique in many features of its coastal Pacific life." The truth of this statement with particular reference to earthquakes will be considered in this paper.

As already announced,[2] the United States Weather Bureau is now conducting seismological work. As planned originally, the work thus far has consisted principally of a systematic collection of non-instrumental observations, and their publication in the *Monthly Weather Review*. The Bureau has in operation a Marvin (vertical pendulum) seismograph at Washington, D. C., and a pair of Bosch 25-kilogram horizontal pendulums at Northfield, Vermont. Moreover, the Bureau has the kind cooperation of practically all other seismic observatories in North America, from Panama to Alaska. The work is being carried on under the supervision of Professor William J. Humphreys.

As the Weather Bureau has not yet installed a seismograph in California, the work in this state has thus far been seismologic, rather than seismographic. In other words, the work here has been concerned almost entirely with sensible earthquakes,—those having an intensity of II or higher in the Rossi-Forel scale. These earthquakes alone form the basis of this discussion.

Count de Montessus de Ballore, who has perhaps done more than any other seismologist in the collection of earthquake statistics, has concluded that of the two classes of earthquakes, seismologic and seismographic, the former are the more worthy of consideration.[3] Seismographs sometimes record earthquakes which are of artificial origin, or are due to the wind or the surf, and are therefore not earthquakes in the usual sense. Moreover, they frequently record vibrations from distant shocks which are not directly related to the seismicity of the region in which the instrument is located. It is thus apparent that seismographic records are apt to err in excess. Seismologic records, on the other hand, include sensible earthquakes only, these alone being the ones with which the public at large is concerned. Records of this nature are more likely to have an error due to deficiency, since light, though sensible, shocks occurring during the night may pass unobserved.

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[1] Henry Fairfield Osborn, *Science*, N. S. **42**, 473, 1915.

[2] *Bulletin Seismological Society of America*, **5**, 63, June 1915.

In California the seismological work is being carried on through the section center at San Francisco. Within the state there are twelve regular Weather Bureau stations and 167 cooperative seismological stations where the observers, most of whom also serve as climatological observers, have volunteered to aid in the reporting of earthquakes. These seismological observers have been provided with printed instructions, together with cards for reporting earthquakes. The climatological stations alone number about 325, and as it is also the custom of such observers to include earthquake reports under the head of "Miscellaneous Phenomena," it is probable that no widely felt earthquake passes unnoticed. The locations of the 179 seismological stations in California are shown in Figure 1. Examined in connection with Figure 2,[4] which shows the distribution of the known faults, it is apparent that the stations are not only pretty generally distributed throughout the state, but that stations are in close proximity to all known faults. The character of the observers deserves special consideration, since in the reporting of earthquakes personal error and other psychological factors play a prominent part. At the twelve first-class Weather Bureau stations the observers devote their entire time to scientific work, and presumably render reliable reports of earthquakes. Because of the scientific experience gained in their daily meteorological observations, the cooperative observers are also above the average in the trustworthiness of earthquake reports. The data collected to date bear ample witness as to their interest in and capacity for the work. It is probable that few, if any, sensible earthquakes which have occurred in California during 1915 have passed unreported. The interest shown by the general public in this new service of the Weather Bureau has not only been gratifying, but it has also made apparent the wisdom of the Bureau in inaugurating the work.

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[3] Dutton, "Earthquakes," 239, 1904.

[4] "Atlas, Report of California Earthquake Investigation Commission," map 1, 1908.

THE OCCURRENCE OF EARTHQUAKES DURING 1915

During 1915 a total of 83 earthquakes occurred in California. Data relating to these are summarized in Table I. Fifty-four, or 65 per cent of the total number, were felt at one station only, while the remaining 29, or 35 per cent of the total, were felt at more than one

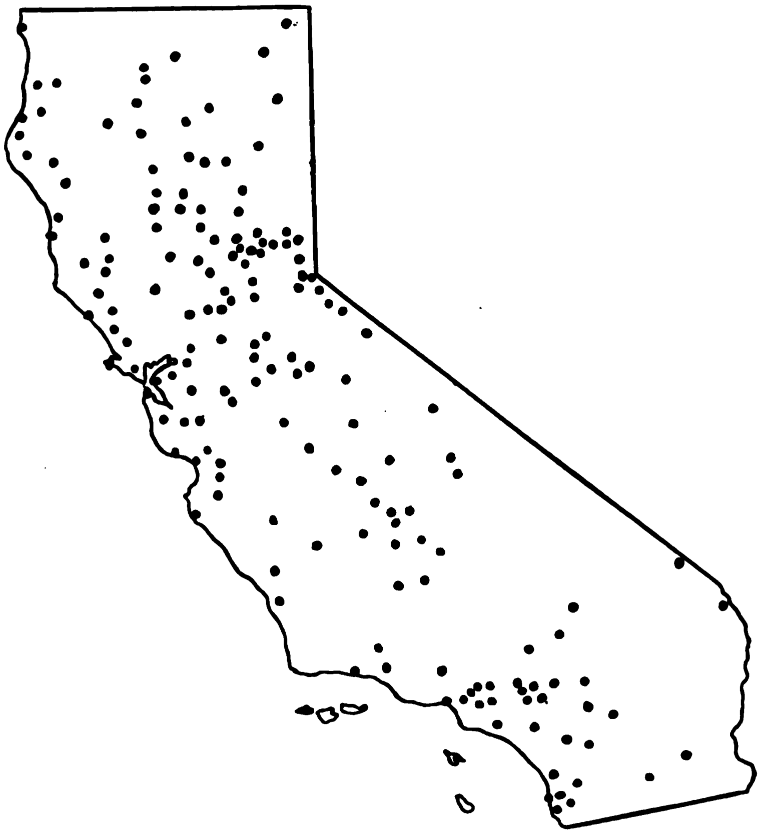

Fig. 1. Outline map of California, showing distribution of U. S. Weather Bureau seismological stations.

station. The monthly distribution of the earthquakes and the reports received were as follows:

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Earthquakes . .	8	5	7	13	9	8	8	3	4	10	4	4	83
Reports received	16	8	7	27	17	35	8	3	7	45	11	15	199

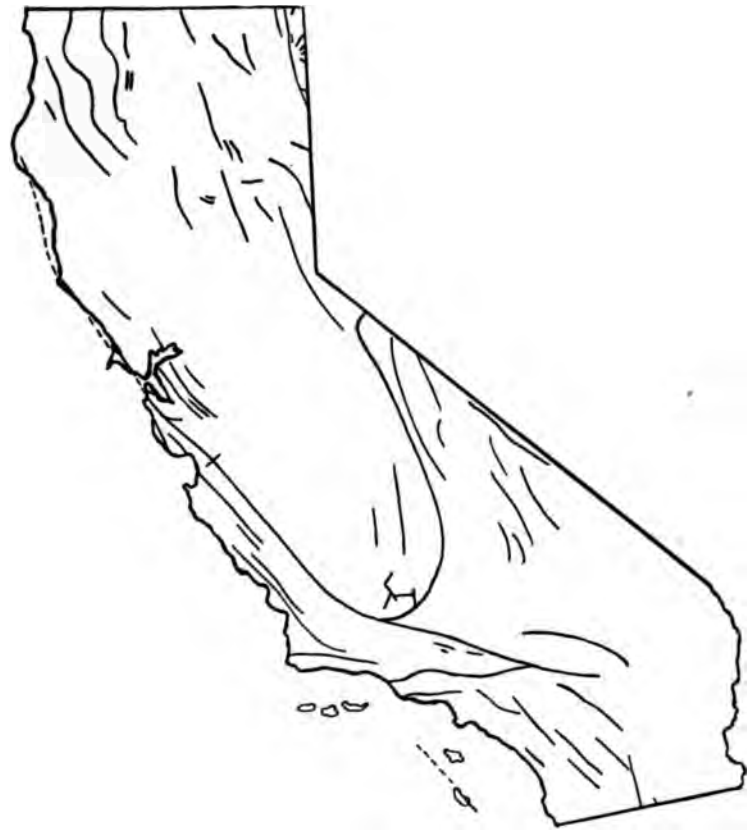

Fig. 2. Outline map of California, showing known faults.

From a study of 768 earthquakes which occurred in California, Oregon and Washington during 1850-1887, Professor Edward S. Holden concluded[5] that for California as a whole, shocks are about equally probable in the wet and in the dry seasons, while in San

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[5] Edward S. Holden, "A Catalogue of Earthquakes on the Pacific Coast, 1769-1897," Smithsonian Miscellaneous Collections, 1087, 12-14, 1898.

TABLE I.—NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1915

Day	Approx. Time 120th Mer. p.m.	STATION	Approx. Lat. (N.)	Approx. Long. (W.)	Intensity R.F.	Number of Shocks	Duration Sec.	Sounds	Remarks
JAN									
11	20 33	Bakersfield	35°22′	119°00′	5	2	5		
11	20 33	Lonoak	36 20	120 55	2	2	2		
11	20 33	Nordhoff	34 35	119 14	3	1	..	Faint	
11	20 33	Ozena	34 53	119 16	5	1	6	Faint	
11	20 33	Paso Robles	35 34	120 40	4	2	5		
11	20 33	San Luis Obispo	35 18	120 39	5	4	30		
11	20 33	Santa Barbara	34 23	119 40	6	1	5	Faint	Lamps swung
12	6 15	Aguanga	33 26	116 51	4	2	4	Rumbling	
12	6 15	Mesa Grande	33 11	116 42	2	1	2	Rumbling	
14	7 30	Rohnerville	40 33	124 11	4	1	2		
14	7 30	Shively	40 25	123 56	3	2	2	Faint	
16	20 53	Coyote	37 14	121 44	3	1	1		
20	11 30	Brawley	32 59	115 40	3	2	1		
26	2 30	Brawley	32 59	115 40	..	..	..		
28	7 00	Brawley	32 59	115 40	2	1	..	Rumbling	
31	0 30	Branscomb	39 40	123 40	3	4	4		
FEB									
16	5 30	Julian	33 05	116 37	5	1	6	Rumbling	
17	3 00	Cahuilla	33 32	116 43	3	1	2	Rumbling	
18	1 47	Eureka	40 48	124 11	2	1	Few		Sudden jolt
18	1 47	Rohnerville	40 33	124 11	4	1	..		
21		Redding	40 36	122 27	7	Many	60		
28	3 00	Arbolado	36 15	121 47	5	2	6	Rumbling	
28	3 00	Hollister	36 50	121 20	4	1	12		
28	3 00	Spreckels	36 20	121 48	3	1	10		
MAR									
1	9 15	Brawley	32 59	115 40	4	1	..	Rumbling	
4	4 50	Julian	33 05	116 37	5	1	8	Rumbling	
12	6 00	Cahuilla	33 32	116 43	4	1	2	Rumbling	
16	19 25	Arbolado	36 15	121 47	3	1	1	Rumbling	
19	10 04	Rialto	34 12	117 27	2	2	4		
29	5 40	China Flat	40 56	123 30	2	1	3		
30	10 00	Brawley	32 59	115 40	2	1	..		
APR									
1	5 25	Julian	33 05	116 37	2	1	6	Rumbling	
1	5 25	Mesa Grande	33 11	116 42	2	1	4	Rumbling	
3	12 00	El Cajon	32 48	116 58	3	1	3	Rumbling	Windows rattled
5	13 45	Bridgeport	38 17	119 16	3	1	3	Rumbling	
5	13 45	Coleville	38 36	119 32	4	1	..	Rattling	
5	13 45	Coulterville	37 42	120 13	3	1	..	Rumbling	Windows rattled
5	15 11	Bridgeport	38 17	119 16	4	1	5	Rumbling	Shook buildings
5	15 11	Camino	38 46	120 41	2	3	..		
5	15 11	Coleville	38 36	119 32	5	2	..	Rumbling	Shook buildings
5	15 11	Coulterville	37 42	120 13	3	2	..	Rumbling	Windows rattled
5	15 11	Markleeville	38 42	119 46	2	2	..	Faint	
5	15 11	Northfork	37 08	119 33	2	1	1		
5	15 11	Sonora	37 59	120 24	3	1	..		

5	15 11	Towle	39°14′	120°48′	3	1	6		Windows rattled
6	8 27	Coyote	37 14	121 44	3	3	4		Windows rattled
6	8 27	Spreckels	36 20	121 48	4	1	5		
6	8 27	Watsonville ...	36 55	121 46	5	1	15	Rumbling	
13	12 09	San Diego	32 43	117 10	2	1	3		
16	22 20	Markleeville ..	38 42	119 46	2	4	20	Rumbling	
16	22 20	Sonora	37 59	120 24	4	1	..	Faint	
20	21 30	Cahuilla	33 32	116 43	3	1	2	Rumbling	
21	2 00	Lonoak	36 20	120 55	2	1	..		
21	2 00	San Luis Obispo	35 18	120 39	3	1	3	Rumbling	
27	19 10	Brawley	32 59	115 40	4	1	2	Rumbling	
29	21 30	Brawley	32 59	115 40	2	1	..		
30	0 20	Brawley	32 59	115 40	5	1	3	Rumbling	People awakened
30	5 45	Brawley	32 59	115 40	3	1	..		Several lighter shocks during day
MAY									
1	13 48	Brawley	32 59	115 40	2	1	..	Faint	Shocks continued from April 30th
2	23 30	Branscomb	39 40	123 40	3	1	..		
3	11 52	Susanville	40 27	120 40	3	2	..	Rattling	Windows rattled
6	4 10	Branscomb	39 40	123 40	5	1	5		
6	4 10	Eureka	40 48	124 11	2	2	5		
6	4 10	Fort Bragg ...	39 23	123 48	5	1	15		
6	4 10	Shively	40 25	123 56	3	2	4		
11	3 45	Cahuilla	33 32	116 43	4	1	..	Rumbling	
11	3 45	Campo.........	32 38	116 28	4	1	..	Rattling	
11	3 45	Julian	33 05	116 37	5	1	8	Rumbling	Light shock 45 minutes earlier
11	3 45	Nellie	33 22	116 52	3	1	5	Rumbling	
13	4 00	Aguanga	33 26	116 51	3	1	10	Faint	
28	10 30	Glennville	35 40	118 45	2	1	..		Shook houses
28	10 55	Bakersfield	35 22	119 01	5	2	3		Rocking motion
28	22 45	Fresno	36 43	119 49	2	1	..		Felt from Merced to Bakersfield
28	22 45	Hot Springs ..	35 56	118 34	3	3	4		
28	22 45	Lone Pine	36 37	118 01	5	2	8	Rumbling	
JUNE									
4	13 10	Shively	40 25	123 56	5	3	1		
6	9 51	Coyote	37 14	121 44	..	..	3		
6	9 51	Oakland	37 47	122 15	4	1	2		
6	9 51	San Francisco..	37 48	122 26	4	1	..		
15	12 55	Chester	40 18	121 15	2	2	..		
17	8 13	San Jose	37 19	121 47	4	..	1		
18	7 05	Avalon	33 27	118 22	5	1	1		
18	7 05	Los Angeles ..	34 03	118 15	4	1	..		
18	7 05	San Pedro	33 45	118 14	4	3	..		Rattled windows
18	7 05	Santa Monica..	34 00	118 30	5	1	5		
19	7 15	Avalon	33 27	118 22	2	1	1		
22	20 00	Barrett Dam ..	32 43	116 46	5	1	..		
22	20 00	Beaumont	33 55	117 00	3	2	1		
22	20 00	Bonita	32 40	117 03	4	1	5		
22	20 00	Blythe	33 35	114 38	2	2	60		
22	20 00	Brawley	32 59	115 40	8	1	60	Rumbling	Walls cracked
22	20 00	El Cajon	32 48	116 58	4	1	30		
22	20 00	Indio	33 43	116 12	6	1	30		
22	20 00	Julian	33 05	116 37	3	1	5	Rattling	
22	20 00	Los Angeles ..	34 03	118 15	2	1	..		
22	20 00	Nellie	33 22	116 52	3	2	6	Faint	
22	20 00	Oak Grove	33 26	116 51	5	2	24		
22	20 00	Sterling	32 49	114 50	4	1	10	Rumbling	
22	20 56	Barrett Dam ..	32 43	116 46	5	1	10		

Day	Approx. Time 120th Mer. p.m.	STATION	Approx. Lat. (N.)	Approx. Long. (W.)	Intensity R.F.	Number of Shocks	Duration Sec.	Sounds	Remarks
22	20 56	Blythe	35°35′	114°38′	2	1	1		
22	20 56	Bonita	32 40	117 03	4	1	5		
22	20 56	Brawley	32 59	115 40	8	1	60	Rumbling	Walls cracked
22	20 56	El Cajon	32 48	116 58	4	2	30		
22	20 56	Indio	33 43	116 12	4	2	..		
22	20 56	Julian	33 05	116 37	3	1	35	Rattling	
22	20 56	Los Angeles ..	34 03	118 15	3	..	..		
22	20 56	Nellie	33 22	116 52	3	2	6		
22	20 56	Oak Grove ...	33 26	116 51	5	1	12		
22	20 56	Sterling	32 49	114 50	5	1	10	Rumbling	
22	20 56	Redlands	34 04	117 12	2	1	..	Faint	
JULY									
3	15 45	Brawley	32 59	115 40	..	..	..		
12	21 43	Victorville	34 32	117 18	..	..	..		
15	10 00	Drakesbad	40 28	121 29	2	1	..	Faint	
21	16 00	Drakesbad	40 28	121 29	3	1	..	Rumbling	
22	3 00	Mineral	40 21	121 32	2	2	..		
22	12 36	Eureka	40 48	124 11	2	1	5		Shook chandeliers
27	11 43	Newhall	34 22	118 30	2	2	1		
27	14 41	Newhall	34 22	118 30	2	1	0.5		
AUG									
5	8 30	Drakesbad	40 28	121 29	5	1	1	Rumbling	
5	10 33	Spreckels	36 20	121 48	3-4	2	2		Windows rattled
6	10 40	Mineral	40 21	121 32	2	1	2		
SEPT									
5	18 20	Mesa Grande..	33 11	116 42	4	1	1	Loud	
7	23 42	Point Loma ...	32 43	117 15	5	1	..	Rumbling	Swayed buildings
7	23 42	San Diego	32 43	117 10	2	1	3		People awakened
8	4 45	Coalinga	35 19	120 20	4	2	8		
8	4 45	Paso Robles ..	35 34	120 40	4	1	4		
8	4 45	San Luis Obispo	35 18	120 39	2-3	2	20		
29	5 00	Yorba Linda ..	33 51	117 50	3	1	..		
OCT									
1	7 26	Livermore	37 40	121 45	2	1	..		
1	7 26	Oakland	37 47	122 15	2	1	2		Chandeliers swayed
1	7 26	Petaluma	38 15	122 38	4-5	2	..		
1	7 26	San Francisco..	37 48	122 26	3	1	5	Rattling	
1	7 26	San Jose	37 19	121 47	2	1	3		
2	17 50	Camptonville ..	39 23	121 04	4	1	30		
2	22 56	Alturas	41 32	120 30	..	..	..		
2	22 56	Bridgeport	38 17	119 16	4	2	..		
2	22 56	Camptonville ..	39 23	121 04	4	1	..		
2	22 56	Chester	40 18	121 15	2	2	..		
2	22 56	Chico	39 40	121 40	2	2	30		
2	22 56	Coleville	38 36	119 32	4	1	..		
2	22 56	Colgate	39 22	121 14	2	1	..		
2	22 56	Colusa	39 12	122 00	5	2	..		
2	22 56	De Sabla	39 50	121 37	..	1	15	Rattling	
2	22 56	Donner	39 17	120 21	..	1	5		
2	22 56	Fort Bidwell ..	41 51	120 08	4-5	1	60		Many awakened by shock

2	22 56	Fresno	36°43′	119°49′	3	2	10		Windows rattled
2	22 56	Gold Run	39 12	120 50	2	1	..		
2	22 56	Lathrop	37 51	121 17	4	1	20		
2	22 56	Lindsay	36 13	119 06	2	..	..		
2	22 56	Lonoak	36 20	120 55	2	1	..		
2	22 56	McCloud	41 17	122 09	3	1	..		
2	22 56	Markleeville ..	38 42	119 46	1	1	20	Rumbling	
2	22 56	Magalia	39 45	121 36	..	1	60		
2	22 56	Nevada City ..	39 17	121 01	..	..	..		
2	22 56	Oroville	39 29	121 39	..	..	..		
2	22 56	Sacramento ...	38 35	121 30	5	3	18		
2	22 56	San Jose	37 19	121 47	5	1	5		Clocks stopped
2	22 56	Stockton	37 57	121 22	2	1	..		
2	22 56	Tallac	38 56	120 03	..	..	..		
2	22 56	Woodfords	38 47	119 49	5	2	14	Faint	
7	21 25	Peachland	38 23	122 46	3	1	5	Rumbling	A few awakened by shock
7	21 25	Oakland	37 47	122 15	4	3	1	Rattling	
7	21 25	Petaluma	38 15	122 38	4	1	..	Rumbling	
7	21 25	Sebastapol	38 23	122 46	3	1	..		
7	21 25	San Francisco..	37 48	122 26	4	2	10		
7	21 25	Tamalpais	37 56	122 35	3	1	10		
7	21 35	Oakland	37 47	122 15	3	1	2	Rattling	
7	21 35	San Francisco..	37 48	122 26	2	1	2		
8	13 20	Petaluma	38 15	122 38	4	1	..		
9	21 06	Redlands	34 04	117 12	4-5	1	2		
20	0 15	New Meadows.	44 57	116 18	2	1	..		
21	22 18	Oakland	37 47	122 15	3	1	2	Rattling	
23	21 26	Holcomb Valley	34 17	117 05	..	..	..		
NOV									
1	2 30	San Francisco..	37 48	122 26	2	2	..		
20	16 15	Aguanga	33 26	116 51	..	1	15		Rocking movement
20	16 15	Blythe	33 35	114 38	2	1	30		Rocking movement
20	16 15	Brawley	32 59	115 40	..	..	..		
20	16 15	El Cajon	32 48	116 58	5	3	10	Rumbling	Trembling movement
20	16 15	Los Angeles ...	34 03	118 15	2	1	60		
20	16 15	San Bernardino	34 06	117 17	2	1	60		
20	16 15	San Diego	32 43	117 10	2	1	60		
20	16 15	Tustin	33 50	118 00	3	2	40		Rocking movement
20	19 00	El Cajon	32 48	116 58	4	1	10	Rumbling	
25	5 45	Julian	33 05	116 37	2	1	3	Rumbling	
DEC									
1	6 05	Corona	33 50	117 36	3	1	..		
1	6 05	Holcomb Valley	34 17	117 05	2	1	..		
1	6 05	Redlands	34 04	117 12	3-4	1	..	Rumbling	Trembling movement
1	6 05	Riverside	33 58	117 26	3	1	..		
14	7 00	Redlands	34 04	117 12	3	1	1		Bumping motion
14	7 00	San Bernardino	34 06	117 17	3	1	..		
26	23 24	Abbotts	36 14	121 28	3	1	..		
26	23 24	Lonoak	36 20	120 55	3	1	..		Rocking movement
26	23 24	Salinas	36 41	121 40	3	1	..		
26	23 24	San Jose	37 19	121 47	3	1	..		
26	23 24	Santa Cruz	36 58	122 02	5	1	10	Rumbling	Rocking, twisting wave motion
26	23 24	Spreckels	36 20	121 48	5	2	..		Rocking, trembling movement
26	23 24	Watsonville ...	36 35	121 38	5	1	10	Rumbling	Rocking motion
31	4 15	Eureka	40 48	124 11	2	..	..		
31	4 15	Shively	40 25	123 56	3	1	2		Trembling motion

Francisco alone they are considerably more frequent in the rainy season than in the dry. As shown above, the earthquakes which occurred during 1915 in California were about equally divided between the wet and the dry seasons.

During the past year California alone experienced more earthquakes than all the rest of the United States. Though it contains but 5 per cent of the area of the whole country, it had more earthquakes than the remaining 95 per cent of the area. Up to November 1st California had 75 separate and distinct shocks, while but 68 shocks were reported from the rest of the United States. A region of high seismicity derives its instability from a number of causes, among which the following are the most important:[6] (*a*) folds in the earth's crust, either emerged or submerged; (*b*) marked variations of topographic relief; (*c*) great ranges between ocean bottoms and adjacent mountain tops, as found where high mountains are close to a coast where the ocean bottom slopes precipitously to great depths; and (*d*) regions where secular elevation or depression is still in progress. All of these features are present in California, and collectively explain its relatively high seismicity. It might be appropriate to add that most seismologists now agree that there is complete independence between seismicity and vulcanicity. The Milne-Omori investigation of 8300 Japanese earthquakes occurring between 1885 and 1892 showed little relation between earth shocks and volcanoes.[7] Only about three per cent of Japanese earthquakes are of volcanic origin.[8]

However, California is not homogeneous in its seismicity. This might naturally be inferred both from the distribution of faults, as shown in Figure 2, and also from the various conditions enumerated in the preceding paragraph. While it is recognized that one year's records offer too meager a basis for a determination of epicenters and the relative seismicity of the various parts of the state, the data are interesting, nevertheless, and, when added to those which will be collected during the coming years, will help to make possible the drawing of a seismotectonic map of considerable accuracy. Figure 3 is an outline map of California showing graphically the number of earthquakes reported from each of the stations during 1915. While the total number of earthquakes reported in the state appears large, the number which occurred at any one station, with a few notable exceptions, was very small.

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[6] Montessus de Ballore, "Relation entre le Relief et la Sismicité," *Comptes Rendus*, **110**, 1183-1187, 1895.

[7] *Seismological Journal of Japan*, **15**, 1895.

[8] Dutton, "Earthquakes," 256, 1904.

The time of occurrence of each earthquake as given in Table I is the approximate Pacific, or 120th Meridian, time. Since the time stated by an observer is simply that taken from a pocket watch or from a household clock great accuracy can not be expected. Though it would be extremely desirable, the Bureau has not yet been able to determine the speed of propagation, even though 29 of the shocks were reported from more than one station. The difficulty of this problem is obvious. As pointed out by Professor Hobbs,[9] "the errors common to any timepieces other than those electrically controlled

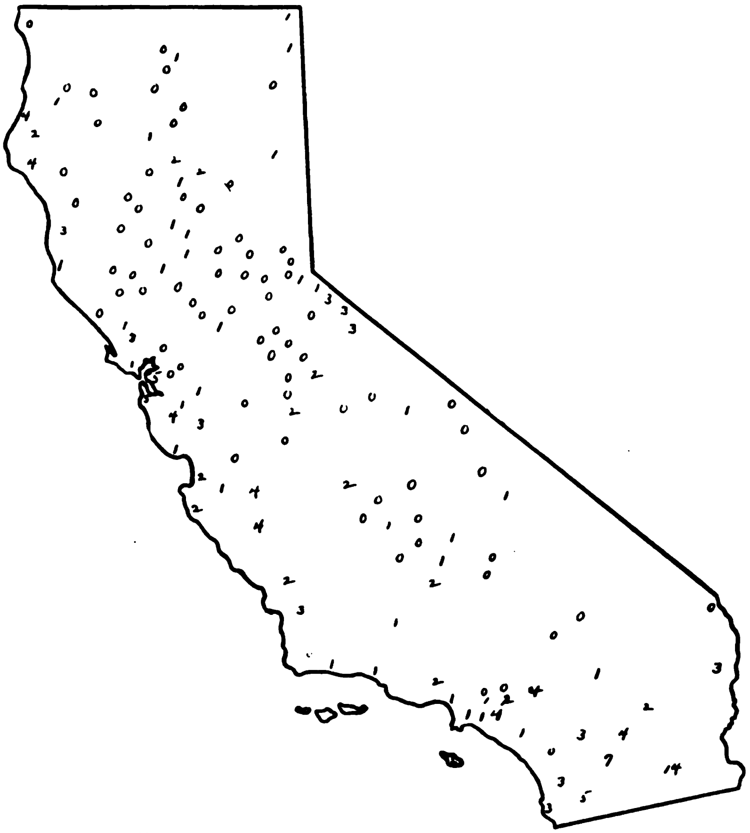

Fig. 3. Outline map of California, showing number of earthquakes reported during 1915.

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[9] Hobbs, "Earthquakes," 20, 1907.

from a central station are such as clearly to destroy the value of the data for the purpose in view." It is well known that the rate of propagation differs for different media, that is, that the velocity of a wave differs for alluvial surface strata, rock interior strata, and water. That these differences are sometimes great may be noted in a comparison of the following instances: From a study of the California earthquake of January 8, 1857, Dr. Trask showed[10] that the average rate of the wave outward from San Francisco was 6.2 miles per minute, or 545.6 feet per second. On the other hand, a vastly different result is apparent from an incident which occurred in connection with one of the vibrations which followed the great shock of April 18, 1906.[11] At 10:06 a.m. on that date, a telephone conversation was in progress between the Weather Bureau observers at Point Reyes and Southeast Farallone Island, the latter being 20 miles due south of Point Reyes, and 26 miles west of the beach at San Francisco. A cable formed a direct connection between the two stations. An earthquake first noted at Point Reyes was felt at the Island three seconds later, indicating an average rate of propagation of 6.7 miles per second.

When the 83 earthquakes which occurred during 1915 were plotted as to the hour of their occurrence it was observed that the curve showed two maxima and two minima. Its similarity to the curve of mean hourly barometric pressure was apparent. Realizing that one year is too short a period to establish the mean hour of occurrence of earthquakes in California, all available records which give an unquestionable hour of occurrence have been tabulated and the results have been plotted. A total of 1405 California earthquakes of intensity II R. F. or higher, and occurring from 1769 to 1915, inclusive, are included in the following, in which the figure given in Line B is the number of earthquakes which occurred during the hour following that indicated by the figure immediately above in Line A.

A	M'D'T	1A	2	3	4	5	6	7	8	9	10	11A	
B	66	61	65	68	81	82	79	52	53	44	52	47	
A	NOON	1P	2	3	4	5	6	7	8	9	10	11P	TOTAL
B	53	51	43	38	57	32	34	54	56	70	77	90—	1405

In Figure 4 are plotted the curves of the mean hourly frequency

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[10] *American Journal of Science*, **25**, 146.

[11] Alexander G. McAdie, "Catalogue of Earthquakes on the Pacific Coast, 1897 to 1906," Smithsonian Miscellaneous Collections, 1721, 50, 1907.

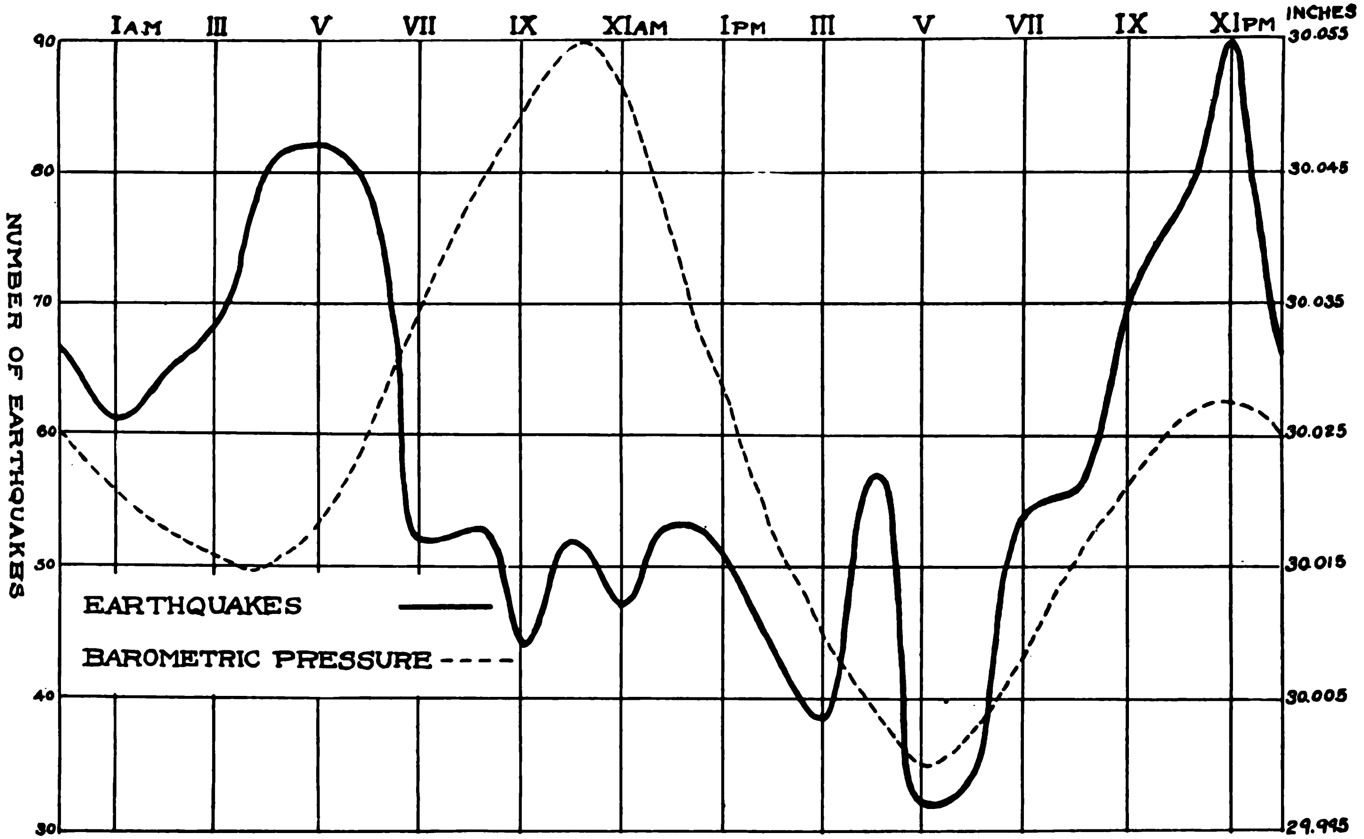

Fig. 4. Curves showing the times of occurrence of 1405 California earthquakes and the mean hourly barometric pressure at San Francisco.

of California earthquakes, based upon 1405 cases extending over a period of 147 years, and the mean hourly barometric pressure (sea-level) for San Francisco, based upon records of 38 years.[12] California earthquakes are thus apparently less frequent during the daylight hours than during the night hours. They are least frequent between 5 p.m. and 6 p.m., and most frequent between 11 p.m. and midnight. A secondary maximum occurs about 5 a.m. The curves of hourly earthquake frequency and barometric pressure are similar in certain respects and unlike in others. The 5 p.m. minimum and the 11 p.m. maximum are coincident in time. While both show maxima during the morning hours, the barometric maximum follows that of earthquakes by about five hours.

INTENSITY

The formula for seismicity involves the factors frequency and intensity. Of the two, the former carries the greater weight. It is generally recognized that the regions of most frequent earthquakes are also the regions having the severest shocks. Moreover, it is known that the intensity of an earthquake is directly proportional to the area shaken: in other words, the heavier the shocks, so much larger will be the area over which they will be felt.[13] Generally speaking, therefore, the intensity of shocks varies inversely as their frequency. In other words, the more common shocks are the lighter shocks, and these are felt at one station only. Of the 199 reports of earthquakes received during the year 1915 in California, the number corresponding to each intensity in the Rossi-Forel scale was as follows: II, 53; III, 51; IV, 39; V, 35; VI, 2; VII, 1; VIII, 2; IX, 0; X, 0; and "blank," 16.

Professor Holden pointed out the fact that for any particular locality the number of really heavy shocks was quite small.[14] The international reputation which certain California cities bear as earthquake centers is, to a certain degree, unmerited. Thus at San Francisco there have been but three destructive shocks and four exceptionally heavy earthquakes in a hundred years, although there have been very many slight shocks and tremors. For the state at large the most destructive earthquakes in recent times have been those of 1800, 1812, 1872, and 1906. The year 1915, though it contained some exceptionally heavy shocks, was probably an average year from a seismological standpoint. As the more important have already been discussed in detail elsewhere, individual earthquakes will not here be enlarged upon. The most severe and widespread earthquakes of the year in California were those of January 11th,[15] June 22d,[16] October 2d,[17] and October 7th.[18] The Imperial Valley earthquake of June 22d was accompanied by loss of life and the destruction of property both in California and adjacent portions of Mexico. The earthquake of October 2d, estimated to have been as severe as that of the San Francisco earthquake of April 18, 1906, was felt from Baker, Oregon, to San Diego, California, about 800 miles north and south; and from the Pacific coast to Salt Lake City, or about 650 miles east and west. The center of this disturbance was along a fault on the eastern border of Pleasant Valley, Nevada.

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[12] Alexander G. McAdie, "The Climate of San Francisco," *Weather Bureau Bulletin*, No. 499, 26, 1913.

[13] Montessus de Ballore, "Les Tremblements de Terre," 1906.

[14] Edward S. Holden, "A Catalogue of Earthquakes on the Pacific Coast, 1769-1897," Smithsonian Miscellaneous Collections, 1087, 30, 1898.

NUMBER OF SHOCKS

The typical earthquake consists of a series of preliminary tremors, one or more maxima, and a series of subsequent tremors. Reliable statements concerning the number of these maxima in any particular earthquake are, for psychological reasons, difficult to obtain. Concerning the attempts to secure such data in connection with the San Francisco earthquake of 1906, the California Earthquake Investigation Commission reported as follows:[19] "Many of these replies are rather questionable scientific evidence, inasmuch as many of them were in response to a leading and suggestive question, and very few of them have been subjected to the clarifying process of cross-examination."

The 199 reports of California earthquakes during 1915 were found to testify as follows: 1 shock, 133 reports; 2 shocks, 40 reports; 3 shocks, 8 reports; 4 shocks, 3 reports; "many" shocks, 1 report; and "blank," 14 reports. Thus it is apparent that the great majority of earthquakes consisted of but one sensible shock or maximum vibration.

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[15] *Bulletin Seismological Society of America*, 5, 14-25, March 1915.

[16] Ibid., 130-149, September 1915.

[17] Ibid., 190-205, December 1915.

[18] Ibid., 230-235, December 1915.

[19] "Report of California Earthquake Investigation Commission," 1, Part II, 374, 1908.

Duration of Shocks

The exact determination of the duration of a perceptible vibration requires an acute observer equipped with a chronometer. While the reports included in Table I do not presume such a high degree of accuracy, their testimony as to the duration is interesting, nevertheless. Estimates varied from a fraction of a second to 60 seconds. By actual count they consisted as follows: 1 second or less, 16 reports; 2 seconds, 17 reports; 3 seconds, 11 reports; 4 seconds, 8 reports; 5 seconds, 18 reports; 6 seconds, 7 reports; 8 seconds, 4 reports; 10 seconds, 12 reports; 11 to 15 seconds, 7 reports; 16 to 20 seconds, 5 reports; 21 to 30 seconds, 8 reports; 35 seconds, 1 report; 40 seconds, 1 report; 60 seconds, 9 reports; and "blank," 75 reports. The relatively large numbers of estimates of 5 seconds, 10 seconds and 60 seconds are readily explained in psychological terms. The most frequent duration of a sensible vibration was apparently from 1 to 2 seconds.

It has been pointed out that the longer the duration of an earthquake vibration the greater will be its destructive effects.[20] This is well borne out by the fact that the two heaviest and most destructive shocks of the year, those of intensity VIII R. F., which occurred in the Imperial Valley on June 22d, each were estimated as having been 60 seconds in duration. On the other hand, most of the lighter shocks, those felt at one station only, were of but 1 to 3 seconds in duration.

Sounds

Regarding sounds, the cards on which the observers report earthquakes read as follows: "Sounds: No, Yes. Before, with, after shocks. Faint, loud, rumbling, rattling." The observer is expected to cross out the inappropriate words. In this connection the same remark may be made as was stated above in connection with the number of shocks. However, the reports are not to be disregarded on this account.

Without reference as to their occurrence before, with, or after the shocks with which they were associated, the 199 reports were divided as follows: No, 132 reports; yes, 67 reports. The latter were divided as follows: Faint, 12 reports; loud, 1 report; rumbling, 44 reports; and rattling, 10 reports.

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[20] *Bulletin Seismological Society of America*, 5, 182, December 1915.

When sounds accompany earthquakes in California they are usually sounds of low pitch, that is, of relatively slow vibrations. Personal equation enters prominently into reports of this nature. It is a well recognized fact among psychologists that people differ widely as to the range of audibility. Earthquakes which produce sounds observed by some persons may therefore be apparently without sound to others.[21]

The cards used by the earthquake observers have a line for reporting the direction of vibration. As it is recognized that personal impressions of direction of earthquake vibrations are untrustworthy,[22] that phase of the subject will not here be considered.

General Considerations

During the past year and a half Mount Lassen (Lat. 40° 25′ N., Long. 121° 45′ W.) has been an active volcano, with more than one hundred observed eruptions. Whether or not there has been any relation between the eruptions of Mount Lassen and California earthquakes, has been a much debated question. As shown in Figure 1, the Weather Bureau has numerous seismological observers within a comparatively short distance of the mountain, while Figure 3 shows that the number of earthquakes reported in that vicinity was not large, comparatively speaking. It might be inquired whether the presence of an active volcano would tend to increase or to decrease the number of earthquakes in the vicinity. Humboldt found a tradition among the natives of South America that so long as the volcanoes in their neighborhood were active, no danger from earthquakes need be feared, but if these remained quiescent for a long-continued period severe earthshocks might be anticipated. In a manner the volcano acted as a safety-valve, according to the tradition. So far as it has been possible to determine, not a single earthquake occurred in northern California simultaneously with an eruption of Mount Lassen, several press dispatches to the contrary, notwithstanding. As a matter of fact, that part of the state farthest distant from Mount Lassen had the heaviest as well as the most numerous earthquakes during 1915. The Imperial Valley, here represented by Brawley, experienced 14 observed earthquakes during the year. (Though the Bureau has but one seismological station in the Valley thus far, efforts have already been made to increase the number.) With the exception of the Imperial Valley, shocks were less numerous in the interior than along the coast. Throughout the entire course of the San Andreas rift, from its extreme northerly limit near Eureka, to its detached southerly extensions in the Imperial Valley, earthquakes were relatively numerous. There is a conspicuous parallelism in California, along NW-SE lines, of sea coast, mountain chains, interior valleys, fault lines and earthquakes. One exception to the general rule regarding earthquakes is noteworthy. It has been observed that "the places of origin of a considerable group of earthquakes are so distributed along a line trending east and somewhat north from the region of San Francisco Bay as to suggest an action of bending, or faulting, or both, in the depths about an axis in this direction. This might be expected if the southern Sierra were rising faster than the northern, and were rising faster at its southern end." [23] Certain California earthquakes suggest recent, and probably progressive, uplift along the eastern scarp of the Sierra. One instance will suffice. At 2:50 a.m. on April 19, 1892, the heaviest earthquake in twenty-four years was felt along a line running from San Francisco to Reno, Nevada, while at short distances on either side the shock was imperceptible to the senses. The center of the disturbance appeared to be between Vacaville and Winters. In both of these towns the intensity was VIII R. F., and great destruction of property resulted. It would appear that the relatively high seismicity of the San Francisco Bay region is the direct result of its location on two different stress planes which cross each other nearly at right angles.

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[21] "Report of California Earthquake Investigation Commission," 1, Part II, 377, 1908.

[22] *Bulletin Seismological Society of America*, 5, 26-29, March 1915.

Lone Pine, California, in the vicinity of Owen's Lake, in Inyo County, has long been recognized as one of the habitual epicenters of the United States. On March 26-27, 1872, 1000 sensible shocks occurred within the period of 48 hours. It is curious to note that during the whole year 1915 but one earthquake occurred at Lone Pine. Apparently an anomaly, this phenomenon may possibly be explained by a migration of the epicenter, such as has been known to occur in Austria. Presumably such a migration takes place along a fault line. The question immediately arises, Has the Lone Pine epicenter migrated to the Imperial Valley, in California, or to Pleasant Valley, in Nevada? Such a movement might easily occur, assuming the extension of known fault lines.

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[23] *Bulletin Seismological Society of America*, 5, 227, December 1915.

All investigations of California earthquakes point to a tectonic rather than a volcanic origin. While local shocks are doubtless local in origin, the great majority are related to faults, some known, others still unsuspected. In addition to the considerations enumerated in the foregoing, a tectonic rather than a volcanic origin is indicated by (*a*) the deep foci of sensible shocks, (*b*) the long periods between the short preliminary tremors and the maximum vibrations, and (*c*) the vast areas over which the heavier shocks are felt.

A discussion of California earthquakes would be imcomplete if it did not attempt to correct certain false notions concerning the danger from earthquakes. While the seismicity of the state is acknowledged to be high—the highest in the United States—the actual danger to one living in any particular locality is small indeed. Though written thirty-five years ago,[24] the following words of General Hardenburg are still true: "Reasoning from the foregoing historical facts, I am firmly of the opinion that the earthquakes of California are not so much to be dreaded as is generally supposed; in fact, that they are far less dangerous to life and property than are the hurricanes of the South, or the summer tornadoes of the North."

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[24] Report of U. S. Surveyor-General, 1871.

San Francisco, Cal.,
February 1, 1916.

AN EARTHQUAKE IN NEW ENGLAND DURING THE COLONIAL PERIOD (1755)

By Frederick E. Brasch

The following reprint is an account of an earthquake which has more than a common and indirect interest. It is presented here primarily for its historical significance: to show the status of the knowledge concerning such phenomena, as well as the progress of the sciences during the colonial period. This probably is the earliest and most authentic description of an earthquake before 1785, the date from which the history of geology (in the United States) is reckoned. There are, however, records of five other prominent earthquakes; but the history and facts concerning them are meager, inaccurate, and consequently unsatisfactory for scientific deduction. The early colonists were without instruments and methods for recording such disturbances, but more especially were lacking in men trained to study the various features of these geologic forces.

Not until John Winthrop, Hollisian Professor of Mathematics and Natural Philosophy at Harvard College (1738-1779), was there any real progress made in American science, especially in the subject of earthquakes. The work of Winthrop as a scholar and a colonial scientist is probably too far removed, and lost to our present generation of scientific men; and for that reason also, it was thought desirable to present this interesting document, with a brief outline of his life.

John Winthrop was born in Boston, December 8, 1714, of a long line of famous forefathers. He graduated from Harvard College in 1732, and six years later was elected to the Hollisian Professorship of Mathematics and Natural Philosophy in that university. He immediately showed great zeal, activity and talent as a teacher, and as an investigator, and for the next forty years his labors were productive of good results. Winthrop was honored by election to membership in the Royal Society (London), also to the American Philosophical Society (Philadelphia). In 1771 he received the LL. D. degree from the University of Edinburgh, and also from his own college. He died in Cambridge, May 3, 1779.

While astronomy claims Winthrop primarily, yet by no means were his services less valuable and limited in other directions; but this cannot at this time be taken up. His lecture upon the phenomena of earthquakes was the result of a popular demand in order to alleviate the fears, superstition and ingnorance concerning such forces. It was given before the students of Harvard College, November 25, 1755, and later printed for distribution. While Winthrop may have separated the idea that such phenomena were the direct expression of the wrath of God, he did not completely overthrow the pluralistic doctrine of nature held so tenaciously by the Puritanic colonists. The text of this lecture is given here in the original in order to show clearly this colonial scientist's ideas, characteristic modes of expression, and how nearly modern he was in the theory he presents. It is a curious intermixture of analytical chemistry, mineralogy, astronomy and geology. He probably is the first scientific man to apply computations to the movements of geologic disturbances. His ideas on the nature of heat, especially concerning the internal actions of the volcanoes and earth movements, were greatly in advance of the science of his day.

Note.—Due acknowledgment is expressed here to the authorities of the Library of Congress and of the Stanford University library, for making the loan of this valuable document possible.

F. E. B.

A
LECTURE
ON
EARTHQUAKES

Read in the Chapel of Harvard-College in Cambridge,
N. E., November 26th, 1755.

On Occaſion of the great Earthquake which
ſhook New-England the Week before.

By JOHN WINTHROP, ESQ.
Holliſian Profeſſor of the Mathematics and
Philoſophy at Cambridge.

Publiſhed by the general Deſire of the Society.

BOSTON: NEW-ENGLAND
1755

A LECTURE ON EARTHQUAKES

You may juſtly expect that the great EARTHQUAKE, which ſo lately[1] ſpread terror, and threatened deſolation throughout New-England, ſhould take me off from my ſtated courſe of lectures, to inquire into the probable cauſes of ſo formidable a phænomenon. The ſubject is curious, and at preſent engages the attention of many perſons; and the diſcuſſion of it may help to extend your views.

An Earthquake, you all know, is an agitation or ſhaking of ſome *conſiderable* part of the earth, and that by *natural* cauſes in contradiſtinction to the ſhaking of a *ſmall* part of it by *artificial* methods. The degrees of this ſhaking are very various from the ſmall jarrings, which are but juſt perceptible, to thoſe violent concuſſions, which have altered the face of the whole countries. Theſe ſhakings are for the moſt part (I believe, always) praeceded or attended by an hollow rumbling noiſe, ſomething like what is called *heavy thunder*; which is uſually greater or leſs according to the degree of the ſhake. Naturaliſts have diſtinguiſhed earthquakes into two kinds; one, when the motion is horizontal, or from ſide to ſide; the other, when it is perpendicular, or right up and down. This diſtinction may, for what I know, be juſt; and yet perhaps earthquakes more commonly conſiſt in a kind of *undulatory* motion, which may include both the others. For as a wave of water, when raiſed to its greateſt height, ſubſides, and in ſubſiding ſpreads itſelf horizontally; ſo in like manner, a *wave of earth*, if I may be allowed the expreſſion, muſt in its deſcent partake both of an horizontal and perpendicular motion at the ſame time. And for the ſame reaſon, it muſt have had both theſe motions in its aſcent; but thoſe particles, which had been carried forward in one direction in the aſcent, will return in a contrary direction in the deſcent. This has been evidently found to be the caſe in the more violent earthquakes; and probably the reaſon why it has not been univerſally found so, was, the difficulty of diſtinguiſhing theſe two motions from one another, when each of them has been but ſmall. Though the ancient *Aegyptians* and *Chaldeans* are ſaid to have been able to foretell earthquakes, yet it is very certain, from all the accounts we have, that theſe agitations of the earth do no where obſerve any order or regular period in their returns; but at ſometimes, recur more frequently; at others, after longer intermiſſions. If therefore they pretended to foretell them at all, they muſt have done it, not from any knowledge they had of their nature and cauſes; but only by the vain arts of judicial aſtrology;—a kind of learning, it ſeems, which, futile as it is, was held in high repute among them. No countries, of which we have any knowledge, are exempt from theſe agitations; but ſome are more ſubject to them than others; and it is obſervable, that thoſe which abound moſt with combuſtible minerals, as foſſile coals, ſulphur, nitre, etc. are the moſt expoſed to them. Many of theſe countries, too, have certain mountains called *vulcanos,* which are almoſt perpetually burning and throwing out fire, and ſmoke, and aſhes; their entrails probably conſiſting chiefly of ſuch ſort of minerals. It is obſerved, however, that about the time of an earthquake in thoſe places, theſe vulcanos rage more furiouſly, projecting ſtones and cinders to a great height in the air; and pouring out whole rivers of liquid fire, which carry ſuch devaſtation, wherever they run, as no human art can either prevent or repair. Several ſuch there are in the *Molucca* Iſlands in the *Eaſt-Indies,* almoſt under the equinoctial; and *Iceland,* under the polar circle, has four or five, beſides the noted *Hecla.* *Veſuvio* near *Naples* is very remarkable; but there is none more famous than that in *Sicily,* now known there by the name of *Monte Gibello,* as it was formerly by that of *Aetna;* whoſe eruptions Virgil has deſcribed in ſo pictureſque a manner.

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[1] This great Earthquake happened on *Tueſday* the 18th of *November*, 1755, about a quarter after four in the morning. There was another much ſmaller ſhock an hour and quarter after this, viz. at $5^h\ 29'$; and a third on the *Saturday* evening following, at 27′ after 8. Since the reading of this lecture, there has been another ſmall ſhock, viz. on *Friday* the 19th of *December* in the evening, exactly at 10 o'clock; the ſky being then perfectly clear, and a very gentle gale at S.W. It was preceded by the peculiar noiſe of an Earthquake about 3 or 4 ſeconds, and the jarring laſted near as long; cauſing the window-ſhutters and door of the chamber, in which I then was, to clatter. Thoſe of my family, who were in a lower room, perceived nothing of the ſhake, though they heard the noiſe. Theſe are the only ſhocks that I have been ſenſible of; though it is ſaid, that many others have been felt in the Province of *New-Hampſhire*, ſince the firſt great one.

God be thanked, all earthquakes are not formidable in ſo high a degree. Thoſe of *New-England,* in particular, which have indeed greatly and juſtly alarm'd the inhabitants, have never deſtroyed them. For tho' this country, we know, has been viſited with earthquakes from its firſt ſettlement by the *Engliſh*; yet, ſo far as my information reaches, not a ſingle life has been loſt by any of them; and perhaps never ſo much damage done to our buildings as by the laſt great ſhock: As to which I would obſerve,

Firſt, That it certainly began with an ***undulation*** of the earth, as I have been aſſured by ſome who were then awake; tho' I think it would not have been eaſily concluded from the effects, that the earth had had any other than an horizontal motion; thoſe effects which were generally taken notice of, being chiefly, if not only, ſuch, as a perpendicular motion would not, but an horizontal one would, have produced. Such, for inſtance, were the daſhing of liquors over the ſides of open veſſels; the overſetting many things in houſes; and the throwing of bricks from off the tops of chimnies to ſome diſtance. In order to eſtimate the velocity with which ſome were thrown from my chimney, I meaſured the greateſt diſtance on the ground to which any of them had reach'd, and found it to be 30 feet; and the height of the chimney from which they fell was 32 feet. Now bodies fall thro' 16 feet nearly in one ſecond of time; and the times in which they fall thro' other heights, are in the ſubduplicate ratio of thoſe heights. From whence it follows, that the velocity, wherewith thoſe bricks were thrown off, was that of above 21 feet in 1″ of time. For the ſubduplicate ratio of 32 to 16 is the ſame as the ſimple ratio of 30 to a little more than 21. It will be impoſſible, I believe, ever to determine with exactneſs the real ſpaces thro' which any of our buildings vibrated, in this reciprocating motion of the earth. It may be obſerv'd, however, that the ſhorter theſe vibrations are ſuppoſed to have been, the quicker or more frequent they muſt have been; the number of them in a given time being reciprocally as the length of each. Thus for example, if each vibration had been of one foot in length, then there were 21 of them in 1″ of time; but if each were 6 inches, then there were 42 of them in a ſecond; and ſo on. Poſſible, ſome of theſe reciprocations might be as quick as thoſe of a muſical chord.

But it is not to be doubted, that the velocity, wherewith our buildings were agitated, was different in different places. It was different alſo, as I apprehend, at different heights. This I collect from the obſervation, that a key, which was thrown off a ſhelf in my houſe, was not thrown ſo far, in proportion to the height thro' which it fell, as the bricks were from the top of the chimney. Hence it appears, that our buildings were ***rocked*** with a kind of angular motion, like that of a cradle; the upper parts of them moving ſwifter, or thro' greater ſpaces in the ſame time, than the lower. This perfectly agrees with the idea of an *undulatory* motion of the earth; as you may clearly conceive by turning your thoughts to the caſe of a veſſel floating at reſt upon ſtagnant water, and then ſuddenly agitated by a great wave rolling under it. In the motion of aſcent, the maſt of the veſſel would be thrown forward, in the ſame direction as the wave was moving; and in the motion of deſcent, backward, or in the contrary direction; and in both theſe caſes, the top of the maſt would move thro' greater ſpaces than the bottom.

As it is certain, that in the great ſhock, the earth had an horizontal motion; so it appears with the moſt ſenſible evidence to me, that in the ſhock we felt the *Saturday* evening following, at 27′ after 8, there was a perpendicular motion of the earth. I was then ſitting on a brick hearth, and felt the motion of the bricks diſtinctly under my feet. It was not a motion of the whole hearth together, either from ſide to ſide, or up and down; but of each brick ſeparately by itſelf. Now as the bricks were contiguous, the only motion, which could be communicated to them ſeparately, was in a perpendicular direction; and the ſenſation excited in me was exactly the ſame, as if ſome ſmall ſolid body, by moving along under the hearth, had raiſed up the bricks ſucceſſively, which immediately ſettled down again. The motion of the earth in this inſtance plainly appeared *undulatory* to me; and this ſhock, I apprehend, was occaſioned by one ſmall *wave of earth* rolling along, but not with a very ſwift motion. For the velocity of its progreſs was conſiderably leſs than that of ſound, which moves about 13 miles in a minute; as appeared from hence, that the roar of this earthquake might be heard at leaſt half a minute before the ſhake was felt. Which alſo argues, that the ſhock began at ſome conſiderable diſtance from this place. The ſame remarks may be applied to the great ſhock; only this began with two at leaſt, if not three *waves*, of much greater breadth and height. The latter part of this ſhock was *tremulous*, conſiſting chiefly in vibrations which ſucceeded one another with extreme quickneſs; and, as I take it, was owing to the efforts of the earth to recover the poſition, out of which it had been violently thruſt, during the undulatory motion; Much in the ſame manner, as the reciprocations of a muſical chord are occaſioned by its endeavors to reſtore itſelf to that ſituation, which it had before it was ſtruck. As ſoon as the ſtroke, which bent it, ceaſes, the chord does not barely regain its rectilinear figure, but bends itſelf almoſt as far the contrary way; and thus continues bending and unbending itſelf with great quickneſs, till it's motion is gradually deſtroyed, and at length it ſettles into a ſtate of reſt. Both theſe ſhocks, then, ſeem evidently to have been of the *undulatory* kind; and to have differed in degree only. I would obſerve

Secondly, that the *duration* of the great ſhock was *longer* than has been uſually obſerved. If my memory fails me not, even thoſe earthquakes, which have brought on the moſt amazing cataſtrophes, have commonly done their execution in one or two minutes; whereas this ſhock with us laſted at leaſt four; taking in the whole of the time, from the firſt agitation of the earth, till it was become perfectly quiet; though the violence of the ſhock did not laſt ſo long. This I am aſſured of, partly from the obſervations of ſome Gentlemen, who were up, and looked on their watches, when it began and ended; and partly from my own, which were as follows. The preceding noon I had adjuſted both my clock and watch, by a meridian line; and the following noon I found that the watch had kept time exactly. Being awakened by the earthquake, I lay till the violence of it ſeemed to be over, for the ſecond time; for it had a little abated before, as if it were going off, and then inſtantly began again with redoubled fury. Till then I forbore to riſe becauſe the agitation was ſo vehement, that I concluded it would be very difficult, if not impractible, to go from the bed to the chimney, without being thrown down; and therefore thought it beſt not to attempt it. The ſpace of time, in which I lay awake, I cannot think to be much, if anything, leſs than 2′. This was the conjecture I formed at the time; though it being but conjecture, I would not lay very great ſtreſs upon it, were it not ſupported by concurring obſervations. On the ſecond abatement I roſe, and lighting a candle, looked on my watch, and found it to be 15′ after 4. The ſhock then was not quite over, but the windows continued rattling for about a minute longer, as near as I can remember; for the ſhock went off very gradually. As ſoon as I had looked on the watch, I went directly to the clock, which was in another chamber, that I might ſee whether that agreed with the watch; and found that it was ſtop'd at 4^h 11′ 35″. It's ſtopping, however, was not, immediately, owing to the violence of the ſhock, though ſeveral clocks, and watches too at *Boſton* are ſaid to have been ſtop'd by it; but to the following accident. Having ſome time before uſed a pretty long glaſs tube, in a particular experiment, I had ſhut it up in the clock-caſe for ſecurity; and this tube, being overthrown by the earthquake, lodged againſt the pendulum, and ſtop'd it's motion. By this accident, the beginning of the earthquake, I conceive, is determined with all the exactneſs that can be deſired; for, ſo far as I can learn, the firſt ſhake was violent enough to overſet ſo tall, ſlender a body, and ſtanding in a poſition ſo near a perpendicular, as that tube; and it was impoſſible for the pendulum to make one oſcillation, after the tube had ſtruck againſt it. Now from the time when the clock ſtop'd, to my looking on the watch, it was about 3′½; and the jarring was not quite over, till about a minute after this: So that I think I ſpeak within bounds, when I ſay, that this ſhock with us laſted at leaſt 4′. In other places it's duration might poſſibly be different. I obſerve

Thirdly, as to the *courſe* of this earthquake, that it ſeems to have been nearly *from N. W. to S. E.* I was informed a few minutes after the ſhock, by a perſon who was upon the *common* in this town at the time, that the noiſe began about the N. W., and came on from thence, and paſſ'd away toward the S. E.; and other accounts, which I have ſince met with, agree with this. Thoſe who were in ſuch clear, open places could make the beſt judgment in this matter; for ſuch as were within doors, or ſurrounded with buildings, might eaſily be miſled by the various reflections of the ſound. I am induced to give the greater credit to this information, by what I obſerved myſelf. For the key before ſpoken of, as thrown from off a ſhelf in my houſe, was found at a place on the floor, which bore very near N. W. of the place from which it fell; though the ſituation of it before it's fall was ſuch, that it might have been thrown in ſeveral other directions as well as that, had the courſe of the earthquake been different.

Having made the obſervations propoſ'd, let us now attempt to trace out the cauſes of theſe great phænomena.

That the agents which are able to produce effects ſo extraordinary as thoſe before recited; which can heave up ſuch enormous maſſes of matter, and put into the moſt vehement commotion vaſt tracts of land and ſea, of many hundred miles in extent;—that the agents, I ſay, which can do all this, and more, muſt be very powerful, will not admit of a doubt. Now we know of nothing in nature more powerful than the particles of certain bodies converted into vapor by the action of fire. Fire then, and proper materials for it to act upon, it is probable, are the principal agents in this affair. And what greatly ſtrengthens the probability is, an observation before-mentioned, that thoſe countries, which have burning mountains, are moſt ſubject to earthquakes; and that theſe mountains rage with uncommon fury about the time when the circumjacent countries are torn with convulſions;—an argument this, that the eruptions of ſuch mountains, and earthquakes, are owing to one and the ſame cauſe. But we muſt be more particular.

1. The earth is not ſolid throughout, but contains within it many large holes, pits and caverns; as is agreed by all Natural Hiſtorians. There are very probably alſo long, crooked, unequal paſſages, which run winding through a great extent of earth, and form a communication between very diſtant regions. Some of theſe cavities are dry, and contain nothing but air, or the fumes of fermenting minerals; in others, there are currents of water.

2. This globe is a very heterogeneous body. Beſides the two grand diviſions of it into ſolid and fluid parts, each of theſe is again diviſible into an indefinite number of others. Although our knowledge of the earth reaches but a little way below its ſurface, yet ſo far as we have penetrated, it appears to be a *compages* of a vaſt variety of ſolid ſubſtances, ranged in a manner which to us ſeems to have not much of regularity in it. Here we find earths, ſtones, ſalts, ſulphurs, minerals, metals, etc. and a great number of inferior ſpecies under each of theſe general heads, blended and intermingled with each other. Many of theſe are combuſtible, or of a texture proper to be turned by fire into flame and vapor. And beſides the pure elementary water, if there be any ſuch, the aqueous parts of the globe receive peculiar tinctures from the beds and veins through which they run; ſo that perhaps there may be almoſt as many ſorts of waters, as there are of ſolid ſubstances. Thus, ſome waters are charged with ſulphureous particles; ſome, with particles of iron; and others, with thoſe of other minerals. And the ſubterraneous rivers and ſtreams, thus impregnated with different particles, may by their confluence, produce an almoſt infinite variety of mixtures in the earth. Probably, this promiſcuous diſpoſition of materials, in the bowels of the earth, may be neceſſary to the growth of bodies in it; for in the judgment of ſome of the moſt eminent philoſophers, particularly the excellent Mr. Boyle, even the hardeſt, inorganized bodies, as ſtones, metals, etc. do, in their proper way, grow within the earth, as truly as vegetables grow on its ſurface, or animals in their parent animals. And to the ſame end ſeems to conduce

3. The heat within the bowels of the earth. Heat, it is well known, is a grand agent in moſt natural productions; and the inner

parts of the earth are ſufficiently furniſhed with it. Some parts indeed, as the vulcanos, are actually on fire and burn; but there is, moreover, an heat without flame, diffuſed through the interior regions of the earth. This is evident from the inſtances of hot ſprings, and from the warmth which is always found at great depths, as in the bottoms of mines.

4. There ſeems to be an inexhauſtible ſource of this heat in the attractive powers, which Sir Iſaac Newton has ſhewn to belong to the particles of matter. For, heat conſiſting in a peculiar kind of inteſtine motion of the parts of bodies; whatever tends to produce this motion in bodies, will cauſe them to grow hot. Now ſuch a motion may be produced, by the particles of different bodies ruſhing together, in virtue of their attractive powers; of which that great man has given a very copious collection of inſtances in the 31ſt *Queſtion* at the end of his *Opticks,* whither I muſt refer you. In ſome of them, not only a very ſudden and violent heat, but an actual flame, is produced, by the bare mixing of two cold bodies together; and that, even without the preſence of the air, which we find abſolutely neceſſary to our culinary fires. So in a remarkable experiment, (firſt made, I think, by Dr. Slare) when a certain 'compound ſpirit 'of nitre is poured on half it's weight of any ponderous oil of vege-'table or animal ſubſtances, the liquors grow ſo very hot in mixing, 'as preſently to ſend up a burning flame.' At the firſt trial, ſo ſmall a quantity, as 'a drachm of this ſpirit, being poured upon half a drachm 'of ſuch oil, *in vacuo,* to ſee what effect would enſue; the mixture 'in the twinkling of an eye made a flaſh like gun-powder, and blew 'up the exhauſted receiver, whoſe diameter was ſix inches, and depth 'above eight; all who were preſent being aſtoniſhed at the unexpected 'event.' There is alſo ſo ſtrong an attraction between iron and ſulphur, that 'even the groſs body of ſulphur powder'd,' continues Sir Iſaac, 'and with an equal weight of iron filings and a little water 'made into a paſte, in a few hours grows too hot to be touch'd, and 'emits a flame. And by theſe experiments compared with the great 'quantity of ſulphur with which the earth abounds, and the warmth 'of the interior parts of the earth, and hot ſprings, and burning moun-'tains, and with damps, mineral coruſcations, etc. we may learn that 'ſulphureous ſteams abound in the bowels of the earth, and ferment 'with minerals, and ſometimes take fire with a ſudden coruſcation 'and exploſion.' But to ſet this curious doctrine in it's full light, it would be neceſſary to repeat that whole *Queſtion*; which indeed

highly deſerves it, would the time permit. For it would then appear, that there is a very great variety of bodies which being mixed together, produce ſo ſtrong an efferveſcence, as to emit inflammable fumes. Thus, to mention one inſtance more, when iron is diſſolving in a mixture of oil of vitriol and common water, there inſtantly ariſes a great heat and violent ebullition, with fumes copiouſly exhaling; which are so very inflammable, that, being ſet on fire, they go off at once like a gun, with a great exploſion. Having thus ſeen what a perpetual ſource of heat there is in theſe powerful active principles, continually operating within the bowels of the earth; let us next inquire, what effects may be expected from it. Therefore

5. It is a known property of heat to expand bodies, to rarefy them, and enlarge their dimenſions; and, when raiſed to an higher degree, to ſeparate their parts, and make them fly from each other; as in ſome meaſure appears already from the inſtances mentioned under the foregoing article. This effect heat has upon ſolid as well as fluid bodies;—upon the hardeſt, as well as the ſofteſt. It is obſervable here, that ſuch particles as cohere by the ſtrongeſt attraction, do moſt forcibly repel one another, when they are once ſeparated by heat. And when the heat is intenſe, and the particles of the heated body are prevented from flying away, till they become thoroughly hot; it will require very ſtrong veſſels to hinder their burſting forth with a violent exploſion. Thus, a ſingle drop of common water, incloſed in a glaſs bubble, and laid upon the fire; as ſoon as it becomes hot, will burſt the bubble, with a report ſcarce inferior to that of a piſtol. And water in larger quantities has been heated to that degree, as to rend in ſunder very ſtrong veſſels of iron, in which it has been endeavored to be confined. What the conſequence then would be, of a great body of water's ſuddenly making it's way into a flaming cavern, whoſe ſulphureous or bituminous fires are not extinguiſhed but enraged by water; and of it's being there, almoſt inſtantaneouſly, converted into vapor; your own imaginations may eaſily repreſent to you. This, it is very likely, has ſometimes been the caſe with reſpect to thoſe famous vulcanos, *Aetna* and *Veſuvio*; both which border on the ſea. You ſee here what water may do; but there are many other bodies, which cohere more ſtrongly, as ſulphur and nitre, for example, whoſe vapor is ſtill more powerful than that of water. This is evident from the compoſition of gun-powder; a very ſmall quantity of which, when turned into vapor, everyone knows, is able to remove any obſtacle that oppoſes its expanſion, and to burſt the firmeſt

rocks. The paſte abovementioned, made of powdered ſulphur and iron filings, if put a few feet under ground, will by degrees cauſe the earth over it to heave and crack, to let out the flame; thus making an artificial earthquake. And therefore, if a water ſaturated with ſulphureous particles, ſhould in its paſſage under ground ſoak into a large bed of iron ore, or a ſtrong chalybeate water into a bed of ſulphur; the mixture would doubtleſs perform *in great,* what this experiment does in miniature. A vitriolic water mixing with iron, if in ſufficient quantities, would be followed with the like effect. But no mixture of this nature appears ſo ſurprizing as Dr. Slare's which did not require ſo much as the preſence of the air to inkindle it. From this ſmall mixture, which was but one drachm and a half, a force was generated in an inſtant, by the mutual colliſion of thoſe active liquors, far exceeding the weight of the atmoſphere that preſſed down the receiver; which in that experiment amounted to about 420 pounds. I ſay, *far exceeding*; for the receiver was not barely raiſed, but 'with 'a much greater force blown up,' as Dr. Slare expreſſes it. We have no right indeed, that I know of, to ſuppoſe all the ſame ſorts of bodies, both ſolid and fluid, in the bowels of the earth, as chemiſtry has furniſhed us with; but ſeveral things induce us to believe, that in thoſe dark receſſes, impenetrable as they are to mortal eyes, bodies are prepared, by a kind of natural chemiſtry, which very much reſemble many of our chemical preparations, and are poſſeſſed of the ſame eſſential properties. To be ſure, there are not wanting, in thoſe lower regions, all the degrees of heat, which a Chemiſt could deſire for any of his proceſſes. If then two bodies, of the like nature as the ſpirit and oil uſed in this experiment, ſhould be mingled together in due quantity, though in the cloſeſt ſubterraneous vault, which neither contained any genuine air, nor could admit any; I need not ſay, that an earthquake muſt be the conſequence.

You have now, I ſuppoſe, before you the general cauſes of earthquakes. You have ſeen that there are in the bowels of the earth inflammable materials, of various kinds, and in large quantities; ſome in the form of ſolid or liquid bodies, and others in that of exhalations and vapors; that there are alſo powerful principles conſtantly at work, which are capable of inkindling theſe materials into an actual flame; and that the vapor generated from ſuch flame will endeavor to expand itſelf on all ſides with immenſe force. If now theſe inflammable vapors be pent up in cloſe caverns, ſo as to find no vent till they are collected in a large quantity; ſo ſoon as they take fire in any part, the flame will ſpread itſelf, wherever it meets with materials to convey it, with as great rapidity, perhaps, as it does in a train of gun-powder; and the vapors produced from hence will ruſh along through the ſubterraneous grottos, as they are able to find or force for themſelves a paſſage; and by heaving up the earth that lies over them, will make that kind of progreſſive ſwell or *undulation,* in which we have ſuppoſed earthquakes commonly to conſiſt; and will at length burſt the caverns with a great ſhaking of the earth, as in ſpringing a mine; and ſo diſcharge themſelves into the open air. Theſe vapors may poſſibly ſometimes infect the air, and bring on peſtilential diſtempers, which have been said to be conſequent upon great earthquakes. Not that I can give credit to all the reports of this ſort, which have been handed about; many of them having been propagated by writers of an aſtrological turn, who have been as ready to attribute diſtempers to the configurations of the planets, and to the appearance of comets, as to earthquakes.

By this time, enough has been ſaid, I ſhould think, to convince you, that the earth contains within itſelf the ſeeds of earthquakes in great abundance. And all theſe things being conſidered, it may ſeem rather a wonder that we have no more earthquakes than that we have ſo many. The cauſes of earthquakes are inceſſantly at work; and although it may require a courſe of years to ripen the proper materials to that pitch, as that they can force for themſelves a paſſage thro' the earth; yet it is reaſonable to expect, that they will from time to time be collected in ſuch quantities, and ferment to ſuch degrees; as to make theſe exploſions unavoidable. As therefore our globe has been ſubject to ſuch concuſſions from the earlieſt accounts of antiquity, we have no room to doubt but that it will continue to be ſo, as long as the preſent frame of nature ſubſiſts. For this we may be aſſured of, that though that impriſoned vapor be diſcharged into the open air, which, by its ſtruggles to eſcape, has cauſed an earthquake, yet the fermenting minerals, from which it was generated, will be continually ſupplying new quantities of the ſame, and then thoſe very minerals may from time to time be re-produced, as they are conſumed; as was before obſerved. Thus we ſee that in the very ſtructure and conſtitution of this globe, proviſion has been made to continue theſe agitations of it, at proper intervals of time, during the whole period of its exiſtence in it's preſent form; and that in every climate, from the equator to the pole. This ſuggeſts a reflection, with which I ſhall cloſe the preſent diſcourse. It is this: That

Though theſe exploſions, and conſequent concuſſions of the earth, have indeed occaſioned moſt terrible deſolations, and in this light may juſtly be regarded as the tokens of an incenſed DEITY; yet it can by no means be concluded from hence, that they are not of real and ſtanding advantage to the globe *in general*. Multitudes, it is true, have at different times ſuffered by them; multitudes have been deſtroyed by them; but much greater multitudes may have been every day benefited by them. The all-wiſe Creator could not but foreſee all the effects of all the powers he planted in matter; and as we find in innumerable inſtances (and the more we know of his works, the more ſuch inſtances we diſcover) that he has eſtabliſhed ſuch laws for the government of the world as tend to promote the good of the *whole,* as we may reaſonably preſume, that he has done it in this caſe as well as others. To me, at leaſt, the argument on this ſide the queſtion, drawn from the general analogy of nature, appears to have more force, than any that I have ſeen offered on the other. For there is nothing, however uſeful, however neceſſary, but what is capable of producing, and in fact has produced, damage, in ſingle inſtances. It were endleſs to particularize here: I shall therefore only mention one or two things by way of ſpecimen. The power of gravity,—a power of ſuch indiſpenſable importance, that without it the ſyſtem of nature could not ſubſiſt a moment, has yet proved the deſtruction of multitudes. The wind, ſo neceſſary for the purpoſes of navigation, as well as to purge the air, which would otherwiſe ſtagnate and putrefy,—how often has it riſen to ſuch a pitch, as to overthrow houſes, and wreck veſſels? by which means thouſands have periſhed. Even thunder and lightning, which, next to earthquakes, are the moſt terrible phaenomena of nature, are yet univerſally allowed to be neceſſary to free the atmoſphere from a certain unwholeſome ſultrineſs, which often infects it. Other inſtances of the like ſort I leave to your own reflections; and would rather obſerve, that the world is governed by *general* laws; and general laws muſt, from the nature of them, be liable ſometimes to do hurt. However, laws of this ſort are ſufficiently vindicated, not only as *wiſe,* but as *good,* if upon the whole they produce a *maximum* of good; (to borrow an expreſſion from the Mathematicians;) and this, it is in the higheſt degree probable, all the laws of nature do. It may be added, that as in the animal body, the evacuations, which are of abſolute neceſſity to maintain life and health, do yet ſometimes run to ſuch extremes as to prove mortal; ſo in like manner, theſe explofions of fubterraneous vapor, whofe effects have fometimes been fo fatal, may, notwithftanding this, be highly conducive, and even indifpenfably neceffary, to the good of this globe in general. The explofions themfelves, as well as the laws, in confequence of which they are produced, may be neceffary on various accounts; and particularly to the carrying on the more fecret and noble works of nature within the entrails of the earth. Let me dilate a little on this matter.

By the inceffant action of gravity and other attractive powers, and by the perpetual confumption of fluids, the earth becomes continually more and more hard, compact and denfe. Now an opennefs or loofenefs of contexture, to a certain degree, in the earth, is neceffary to carry on the operations of nature within it. So that on the fuppofition that mineral, metalline, and other fubterraneous bodies grow within the earth, it fhould feem that the earth muft become gradually lefs and lefs fit for the production of them. Since then the direct, immediate, and moft general effect of earthquakes, is, by fhaking to loofen and difunite the parts of the earth, and to open it's pores, it feems agreeable to reafon to infer that this is the end *primarily* aimed at in thefe concuffions. But you will take notice, that I fpeak here only of *phyfical* or *natural ends*. For though I make no doubt, that the laws of nature were eftablifhed, and that the operations of nature are conducted, with a view, *ultimately*, to *moral* purpofes; and that there is the moft perfect coincidence, at all times, between GOD's government of the *natural* and of the *moral* world; yet it would be improper for me to enter into thefe difquifitions at this time, fince my province limits me to confider this fubject, only in the relation which it bears to *natural philofophy*. It is in the *phyfical* fenfe alone that I fay, the difjoining the parts of the earth, and opening its pores, may be the end primarily aimed at in earthquakes, as fuch mutations in the earth may from time to time become neceffary to the production of fubterraneous bodies; and perhaps this end could not be effectually anfwered by lefs forcible methods. This point may receive fome light if not proof, from the operations of agriculture. We find it neceffary, by ploughing, digging, etc. to break the clods of the ground, to comminute and even pulverize it, in order to fit it for the purpofes of vegetation; and we find it neceffary to renew thefe labors every year. Now the ufe and tendency of thefe artificial operations may bear fome analogy to thofe of the greater operations of nature, which we are fpeaking of. And indeed it is not in the leaſt degree improbable, that ſuch a looſening of the parts of the earth may promote even the growth of vegetables on its ſurface, as well as of minerals in its bowels; it being now well known, that all vegetables, the ſmaller as well as the larger, ſhoot ſome fibers of their roots to vaſtly greater depths, than thoſe to which any of our inſtruments of tillage ever penetrate. This, it is likely, may be one reaſon of the wonderful fertility, for which *Aetna* and *Veſuvio* have been ſo generally and ſo highly celebrated. Again; it may be neceſſary now and then, to have ſuch ſubterraneous vapors, as are generated by fermentation, diſcharged up into the air; as their continuance below, in the caverns of the earth, might be an impediment to thoſe important proceſſes which are there carrying on. But thoſe very vapors, which might obſtruct ſome ſorts of natural proceſſes, while below the ſurface of the earth, may as much advance others, when above it. We know that in many caſes of the fermentation of bodies, eſpecially of ſuch denſe ones as ſalts and minerals, air is plentifully *abſorbed;* and that in many others, it is as plentifully *generated:* So that great part of the exhalations thrown out by earthquakes may be true, permanent air, and deſigned to recruit what has been abſorbed by bodies here on the ſurface. And perhaps the grounds, on which the great Newton founded his 'ſuspicion, that the 'fineſt, the moſt ſubtile, and moſt ſpirituous parts of our air, and 'thoſe which are moſt neceſſary to maintain the life of all things, 'come chiefly from the comets'; may equally ſupport another ſuſpicion, that ſome ſuch particles of air may be derived alſo from ſubterraneous eruptions. For among the almoſt infinite variety of particles which are thrown out of the earth in theſe eruptions, it is moſt likely, that if ſome are noxious, others will be ſalutary. It may alſo be neceſſary from time to time to have the ſubterraneous ſtreams diverted from their former courſes into new ones; partly, that different places in the lower regions may be watered by them; and partly, that the waters themſelves, by paſſing through different beds or chanels, may alter their properties, and convey new tinctures to different places.

But however theſe things may be; whether all the foregoing conjectures be well founded, or not: If theſe exploſions and concuſſions be, as it is next to certain that they are, the neceſſary and inevitable conſequences of ſuch laws of nature, and ſuch powers in matter, as our globe could not well ſubſiſt without; this ought to ſilence all the complaints of thoſe who ſuffer either loſs or terror by them: as well as all the objections, which men of ſceptical minds have been diſpoſed to make upon this head to the order of Providence. It ought, in reaſon, to do this, though we ſhould never be able to point out all the particular advantages reſulting from them. For, it is plain, they may be beneficial in a thouſand other ways, than, we, ſhort-ſighted mortals, may pretend to gueſs at.

To ſum up all in a word: This is a mix'd ſtate; in which there is ſuch a variety of purpoſes, ***natural*** as well as ***moral***, in proſecution at the ſame time, that there may be nothing, perhaps, in the material world, that is ſimply and abſolutely *evil*;—nothing, but what, under the direction of infinite wiſdom, power and beneficence, is, in ſome or other of its conſequences, productive of an over-balanced *good*.

Upon the whole. How 'wonderful in counſel', how 'excellent in working' is that BEING, who can bring good out of the greateſt evils; and can anſwer intentions, the moſt widely differing, by one and the ſame diſpenſation of His providence!

THE END.

REPORT OF THE SCIENTIFIC COMMITTEE ON THE ROSSI-FOREL SCALE

In October 1915 the question of modification of the Rossi-Forel Scale was taken up by the Scientific Committee of the Seismological Society. From the answers to the letters sent out the following report has been prepared by the chairman of the committee:

Replies to the Chairman's circular letter of October 1915 were received from five members of the Scientific Committee, from an ex-president of the society, and from the Acting Superintendent of the U. S. Coast and Geodetic Survey, to whom the matter had been referred by one member of the committee.

The replies may be grouped under the following headings:

I. Concerning the Rossi-Forel Scale published in the BULLETIN:

1. The question of publishing the scale in every number of the BULLETIN is regarded by one correspondent as of questionable utility.
2. The members of the committee who replied were unanimous in recommending that no change be made in the expressions of the Rossi-Forel Scale.
3. As an exception to this recommendation President Branner suggested a few changes which are set forth in the note appended to this report.
4. The replies indicate a prevalent feeling that the Seismological Society of America should conform to the usages of the International Seismological Commission, and not adopt changes which have not been considered and recommended by that body.
5. It is suggested that the Rossi-Forel Scale be accompanied by an equivalent dynamic scale, such as that suggested by Cancani and now in use by seismologists. The President of the Society, in his address at the San Francisco meeting, proposed a scale of intensities capable of instrumental measurement, with the same idea in view. The committee has not yet taken any action upon this matter.

In view of these expressions of members of the committee, it is recommended that the society retain the Rossi-Forel Scale as used by the International Commission without alteration of the original terms; that the recommendations of President Branner be communicated to the United States Delegate of the International Seismological Society for presentation to that body, if it be his pleasure; and that, finally, the Publication Committee be requested to consider whether the publication of the Rossi-Forel Scale in some other form or place in the BULLETIN than that now in vogue would not meet the needs of those who consult the paper.

II. Concerning the publication of the times of earthquakes in the BULLETIN, the members of the committee who made replies in regard to this matter deem it highly desirable that such times be published in Greenwich mean time, midnight to midnight,—the time everywhere used by seismologists.

III. Concerning the preparation of a handbook for those in charge of seismographs, the replies agreed in expressing the desire that such a work should be produced. In a subsequent communication to the chairman of the committee, Dr. Klotz of Ottawa stated that he plans to issue a booklet of tables of the most recent calculations, expressly designed to meet the need referred to.

IV. Among the suggestions presented by members of the committee, is one that the BULLETIN be made, so far as possible, to serve the place among seismologists, irrespective of America, which was occupied by Garland's *Geophysik*. It is also suggested that foreign seismological observatories of international reputation might be induced to present records of earthquakes for publication in the BULLETIN.

Respectfully submitted,

J. B. WOODWORTH,
Chairman of the Scientific Committee.

CAMBRIDGE, MASS., December 23, 1915.

RECOMMENDATIONS BY PRESIDENT J. C. BRANNER CONCERNING CHANGES IN THE STATEMENT OF THE ROSSI-FOREL SCALE.

(Roman numerals refer to the Degrees of the Scale.)

III. Omit the words "direction or," and read "for the duration to be appreciable." Consult *Bull. Seism. Soc. Amer.*, 5 no. 1, p. 26, where it is shown that the impression of persons concerning the direction of a shock is of questionable if not misleading value.

IV. Insert the words "some or a few" between the words "felt by" and "persons," so that the statement reads: "felt by some or a few persons in motion." Insert the word "slight" before the word "disturbances," and the words "rattling of" before the word "doors"; in place of the word "ceilings" write the words "house timbers." The proposed changes would then read: "slight disturbances of moving objects, rattling of doors, windows; creaking of house-timbers."

VI. Omit the words "general ringing of house bells." It is suggested that the omission be made because the house-bells of modern houses are electric bells, and these are not affected by earthquake shocks.

VII. Insert the word "serious" between the words "without" and "damage." The changed clause would then read: "without serious damage to buildings."

X. Write "dislocation" in place of the word "disturbance." The changed clause would then read: "great disaster, buildings ruined, dislocation of the strata."

1915.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado, Jesuit Seismological Service.—Reports nos. 11-12, from November 1 to December 31, 1915; no. 1, from January 1 to January 31, 1916.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, nos. 19-21, from December 1 to December 31, 1915; nos. 510-527, from January 1 to February 29, 1916.

Ottawa, Canada, Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 5-8, from May 1 to May 31, 1915; nos. 21-22, December 1 to December 31, 1915; nos. 1-5, from January 1 to February 9, 1916.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 9-11 (3 bis), from January 1 to February 27, 1916.

From the same station, reports of the seismological despatches received at that station from December 1, 1915 to February 29, 1916.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique, nos. 12-20 bis, from August 27 to December 31, 1915.

EUROPE

Barcelona, Spain, Estacion Sismica.—Reports 19-21, from October 1 to December 31, 1915.

Cartuja, Granada, Spain.—Boletin mensual, nos. 8-11, from August to November inclusive, 1915.

Coimbra, Portugal.—Boletim Sismico do Observatorio da Universidade, nos. 7B-10A, from October 1 to November 30, 1915.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 24-26, from September 1 to September 30, 1915.

SEISMOLOGICAL NOTES

A seismologic station at San Salvador.—The following circular letter is self-explanatory:—

San Salvador, Central America,
January 1, 1916.

Sir:—

I have the honor to inform you that the Seismologic Bureau of the Republic of Salvador is now definitely installed in the environs, and to the south, of the city of San Salvador, on the "Finca Modelo" estate. Its position is 13° 43′ 44″ N. latitude, and $5^h\ 56^m\ 58^s$ longitude west of Greenwich. . . . The instruments of our bureau consist of one Vicentini micro-seismograph, two heavy horizontal Bosch-Omori pendulums, and one Agamennone macroseismometrograph, together with all of the accessories necessary to insure their working properly.

Yours very truly,
Sanz. Gz. Barberena.

Dr. Tams gone to the front.—The following announcement, without date, has been received from the Hauptstation für Erdbebenforschung at Hamburg, Germany:—

I hereby respectfully notify you that the Berichte cannot be sent out from this station until further notice, as Dr. Tams has been called out.

Respectfully,
Prof. Dr. Schütt.

Bahia, Brazil, November 6, 1915.—A light earthquake was felt between four and five o'clock p.m. on the island of Itaparica, just south of the city of Bahia, Brazil. About the same time the shock was felt at the city of Santa Amaro, where it is said to have thrown down the walls of some buildings. No other damage has been reported.

Southern California, November 20, 1915.—A letter from a gentleman living at Calexico enables us to add the following interesting observation to the notes given in our last number:

"I had an unobstructed view of a large expanse of desert country immediately across the international boundary in Mexico, and following the earthquake shock a vast cloud of dust arose slowly from the earth, extending as far as I could see along the horizon. No wind or breeze was blowing at the time."

Central Mississippi Valley, December 7, 1915.—About 12:40 p.m. on December 7th, a sharp earthquake was felt over a wide area having its center near the mouth of the Ohio River and extending into the states of Illinois, Kentucky, Tennessee, Missouri, Arkansas, and Mississippi. No damage has been reported.

Guatemala, Salvador, and Honduras, December 20 to 30, 1915.—A series of disastrous earthquakes occurred in Guatemala, Salvador, and Honduras, extending over a period of ten days or more, near the end of December, 1915. The first reports mentioned some twenty shocks at Guatemala from December 20th to 22d, but no damage was done. Later reports spoke of shocks at Chimaltenango, Escuintla, Amatitlan, and Sacatepequez, all of them in the volcanic region west of the city of Guatemala. On the 27th the town of Gracias in Honduras was partly destroyed, and another shock on the 29th nearly completed its ruin, and four thousand people were left without homes. The villages of Talqua, Las Flores and S. Sebastian, all of them near Gracias, were also demolished. But few lives were lost, however. Shocks continued at S. Salvador, on the 30th, but they were less severe.

The following acount has been received from our colleague, Dr. V. F. Marsters, who wrote from San Jacinto, Honduras, under date of December 31, 1915.

On December 26, 1915, at 5:30 p.m., the western part of the Republic of Honduras was visited by strong earthquake movements that occasioned considerable damage to property, but few cases of injury to people.

The strongest movements were felt in the Department of Gracias, located in the southwest corner of the Republic. According to the scanty newspaper accounts, the severest tremors were felt near and at the Capital of the Department, also known as Gracias. The population of the entire Department is given as 49,000. In the Capital there are probably not more than 2,000 people.

In the town of Gracias, the shock was sufficiently strong to destroy all the dwellings, leaving practically no shelter for the population. They are now camped in the streets, and help is being sent from all parts of the Republic, both by the Government and private subscription.

The wave was sufficiently strong to extend to Las Flores, some fifteen kilometers to the northwest, as well as to Talfua, some twenty kilometers distant. A few buildings were destroyed. The church of Talgua was partially destroyed.

Strong tremors were reported as far to the southeast as Choluteca, a distance of approximately 250 kilometers. The time recorded at Choluteca was 5:25 p.m. The shocks at Choluteca were not strong enough to cause any damage to people or property.

Heavy shocks are reported from La Esperanza, in the Department adjacent to and southeast of the Department of Gracias. The distance from Gracias to La Esperanza is approximately 55 kilometers. Strong movements were also reported from La Paz, due east from La Esperanza, a distance of some sixty kilometers; but these were of less intensity than those of La Esperanza. No damages are reported from these localities.

To the northwest of Gracias a moderately strong shock occurred at Santa Rosa de Copán, Department of Copán. The distance from Santa Rosa de Copán to Gracias is approximately thirty kilometers. At Santa Rosa the first tremor is reported to have been felt at 5:10 p.m., and later at 5:34 p.m. a very much stronger wave caused some damage to buildings, including the telegraph office building.

To the southwest from Gracias, reports have arrived from the town of Ocotepeque, some sixty kilometers distant, stating that a rather strong shock was felt at 5:35 p.m. No damages are reported. At San Jacinto, only a short and weak tremor was reported at 5:40 p.m. In Tegucigalpa, the capital of the Republic and approximately 200 kilometers east-southeast from Gracias, the tremors were sufficiently strong to alarm some people, but no damage is reported.

On the night of December 27th some nine strong shocks were felt in Gracias, but these were strongest in Las Flores and Talgua. Very soon after the shocks of December 26th dense darkness followed, with exceedingly heavy rainfall. The latest reports state that a small area in and about Gracias has sunk sufficiently to place a part of the town under water.

Such data as we now have at hand show that the line of maximum intensity extended from Las Flores on the northwest, thence southeast to and through Gracias to La Esperanza: that is, in a southeast-northwest direction. This line is approximately parallel to the range of mountains known under the names Sierra de Atima and Sierra de Opalaca.

Puget Sound, January 1, 1916.—An earthquake was felt at Seattle at 4:52 p.m. It lasted about ten seconds, but did no damage. Shocks were also felt at Tacoma.

Newport, Oregon, January 5, 1916.—A sharp earthquake was felt at Newport, Oregon, but no damage was done.

England, January 14, 1916.—

The Midlands earthquake of January 14th proves to have been felt much more widely than was at first supposed. Though less strong than several other British earthquakes of the last quarter of a century, it was perceived by a large number of persons on the first and second floors of houses at a great distance from the center. The disturbed area included all England, with the exception of the counties of Northumberland and Durham, the northern half of Cumberland, and the southern counties bounded by a line drawn from Bridgewater in Somerset, by Salisbury, and Guilford, to the mouth of the Thames. It thus includes about 45,000 square miles. From a first rough analysis of the accounts received by him, Dr. Davison concludes that the center of the innermost isoseismal line was not far from Stone, in Staffordshire. The western boundary of the disturbed area, however, is somewhat uncertain.—*Nature,* January 27, 1916, p. 601.

Calexico, California, January 15, 1916.—Mr. Ivan R. Ralston reports that he was awakened by two very distinct earthquake shocks close together, at Calexico, Cal., shortly before two o'clock a.m., January 15, 1916.

Schenectady, New York, February 2, 1916.—A shock was reported at 11:25 p.m. at Schenectady. It is said to have been felt through the surrounding country, and to have been severe enough to rattle windows and to break dishes.

Transylvania, February 1916.—The *London Times* of February 4th says that "several earthquake shocks in Transylvania are reported. At Schaefsburg several chimneys collapsed, and the population fled outside the town."

Panama, February 8, 1916.—Three sharp shocks were felt throughout the Panama Canal zone at 11:14 a.m. on February 8th. No damage was done.

Southern Appalachians, February 21, 1916.—A sharp earthquake or series of shocks was felt through a wide area in the southern Appalachian region about 5:45 p.m., February 21, 1916. Reports came from all parts of east Tennessee from Bristol to Chattanooga, and as far south as Atlanta, Georgia. The whole of the western part of South Carolina was shaken, and also the western half of North Carolina and the southwestern part of Virginia. So far as it can be made out from newspaper reports, the highest intensity was in upper east

Tennessee, near the North Carolina line. The only damage reported is at Newport, Tennessee, where it is said that chimneys were thrown down. Professor C. H. Gordon of the University of Tennessee says the shock lasted one minute at Knoxville,—from 5:39 to 5:40 p.m.

Puget Sound, February 22, 1916.—An earthquake was felt through southwestern British Columbia and northwestern Washington at 3:40 a.m. on February 22d. The shock lasted only a few seconds. Houses rocked, dishes rattled, and in one case the foundation of a house is said to have been cracked.

Volcanic eruption, Equador, March 8, 1916.—The volcano of Tungurahua in the high Andes near Riobamba was reported on March 8th to have been in eruption for several days. The city of Ambato and the surrounding region were in darkness on account of falling ashes.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA.

February 16, 1916.

In the absence of the President, the meeting was called to order by Vice-President Tolman, at 4 p.m. in Room 66, Stanford University, Cal. Directors Durand, Tolman, and Townley were present.

The minutes of the meetings of the Society held on August 4 and 5, 1915, were read and approved.

Professor R. A. Daly, of Boston, and Mr. Charles R. Fletcher, of Los Angeles, were elected to membership in the Society, and the following named institutions were put on the list of subscribers:

Library of University of Idaho, Moscow, Idaho.
Weather Bureau, Library, Chicago, Ill.
Weather Bureau, Library, New Haven, Conn.
Smith College Library, Northampton, Mass.
Weather Bureau, Library, San Francisco, Cal.

The resignation of twelve members was reported by the Secretary.

The Secretary also reported a gift to the Society from Dr. J. C. Branner of $402.95, given to finance the investigation of the earthquake in Imperial Valley, and to pay for the illustrations of Mr. Beal's article on this earthquake. By motion duly made and seconded the Secretary was directed to send a letter of appreciation to Dr. Branner.

Upon motions duly seconded and passed the following committees were appointed:

Nominating Committee	Board of Election
R. S. Holway (chairman)	D. S. Richardson (chairman)
E. F. Davis	B. A. Baird
J. A. Taff	H. L. Haehl
A. C. Lawson	R. L. Rowley
A. H. Palmer	L. Wagoner

The Secretary was directed to look into the matter of holding a meeting of the Society next summer in San Diego in connection with the meeting of the Pacific Coast Branch of the American Association for the Advancement of Science, and to call such a meeting if it seems advisable.

Meeting adjourned at 4:35 p.m.

S. D. Townsley, Secretary.

REPORT OF NOMINATING COMMITTEE

SEISMOLOGICAL SOCIETY OF AMERICA

We, the undersigned members of the Nominating Committee of the Seismological Society of America, appointed on February 16, 1916, hereby make the following nominations for the Board of Directors, to be voted on April 1, 1916:

Ralph Arnold
J. C. Branner
E. F. Davis
F. N. Denison
W. F. Durand
W. H. Hobbs
Otto Klotz
A. C. Lawson
A. G. McAdie
C. F. Marvin
H. F. Reid
R. W. Sayles
W. D. Smith
J. A. Taff
C. F. Tolman, Jr.
S. D. Townley
Otto von Geldern
H. O. Wood
J. B. Woodworth

R. S. Holway (chairman),
E. F. Davis,
A. C. Lawson,
A. H. Palmer,
Nominating Committee.

February 26, 1916.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

O W Y H E E

The Bulletin of the
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VOL. VI JUNE-SEPTEMBER 1916 Nos. 2-3

CALIFORNIA EARTHQUAKES

A SYNTHETIC STUDY OF RECORDED SHOCKS

By Harry O. Wood

Author's Note

This study has been in progress since the early part of 1907. It has been interrupted many times by the pressure of ordinary work, but the delay in its appearance has been due chiefly to the failure of repeated time-consuming efforts to find some practicable scheme for graphical exhibition of the results. None of the graphical schemes tried have been practical for publication and at the same time satisfactory to the writer.

Certain crudities and immaturities may appear which might be absent from a study now fresh from the writer's pen: but these do not so affect the true value of the work as to make necessary a complete revision of it. At best it is an attempt to break ground; and its chief value inheres in the suggestions it offers and the directions it indicates for seismologic work in the future in the province of California and neighboring territory.

Preface

The first settlements of white people in California were made by Spanish missionaries and adventurers a little less than one hundred and fifty years ago. These slowly grew in number, but, until the discovery of gold in 1849, the places occupied were few, spaced out at intervals of many miles, chiefly in a narrow belt of country which bordered the coast. Until very recent years no part of this great territory has been thickly peopled. Even now only small districts are well populated, and tracts of large area are hardly occupied at all. It is obvious, therefore, that the record of natural phenomena here, even of events of striking and unusual character, must be very incomplete.

Nevertheless mention is made of more than a half-dozen disastrous earthquakes, two or three of which were shocks of great power. Also great numbers of small earthquakes are chronicled.

The geographical distribution of these exhibits interesting peculiarities.

The places of origin of the shocks of great energy have seldom or never been identically the same, yet they are related, and important districts have been jeopardized by them more than once. No part of the coast region, nor of that which borders the eastern escarpments of the Sierra, has proved immune. Light shocks are all the time occurring in one part or another of these provinces. Though less affected, the Great Valley also is often visited.

This history is significant. It indicates that earthquakes will continue to occur throughout the territory of California. The great majority of the shocks will be weak, but strong ones will happen at intervals.

Moreover, this land lies within a vaguely limited but well characterized zone,—one of two which girdle the earth approximately along courses of great circles,—in which, during the time that history spans, great earthquakes and small have occurred in far greater numbers than in all other parts of the earth. In a broad way these zones are well defined; and students of physical geology comprehend in part reasons for such belts of weakness in the earth's crust.

In California, then, we have to deal with an earthquake hazard, and the problems raised by it.

Up to now the loss of life caused by earthquakes here has been small—almost incredibly small, even when we think of the reasons for this, namely, that the total population has been small, and sparsely distributed, so that only a very small group has been exposed to any one strong shock (except in 1906); that dwellings commonly have been built of wood, framed in ways that have endured seismic shaking very well; and that in several cases, notably in 1906, the shock has occurred at a time of day when few people were abroad to be caught and crushed under falling debris, or to participate in a general panic. Clearly, as destructive shocks continue to originate here, such fortunate circumstances and such a degree of immunity from death or widespread injury cannot be expected always to prevail. Inevitably population will increase greatly, and in the larger centers wooden structures must give way to other sorts, some of which are likely not to survive seismic effects so well. Shocks are sure to occur, too, at busy hours of the day when throngs of people are in the streets, shops, or other places of assembly.

Though the loss of life in California from earthquakes has been small, there is no need to dwell upon the appalling loss of property occasioned here. The San Francisco fire alone, which was caused directly by the earthquake, as were also all the conditions which facilitated its rapid spread, is sufficient testimony. But there has been much loss besides.

While these dangers from earthquake in California must not be exaggerated,—and in reality the hazard to individuals is comparatively slight,—yet there is need of forethought and of provisions for public protection against the effects of strong shocks.

For effective action we need more extended and more precise knowledge of the phenomena, and of the causes and modes of occurrence of the shocks; of their places of origin and the districts of greatest danger; and, so far as possible, of the expectable times of occurrence. We now know very little about all this, yet beginnings have been made.

Some of the fault zones in which powerful earthquakes have originated and will again originate, have been discovered. Some, surely, remain to be found. We know certain localities and districts that will be shaken greatly whenever a strong shock has origin near them, on account of the character of the underlying ground and their relation to surrounding topographic features. There must be other undiscovered districts of this sort. Prediction of the time of occurrence of future shocks is beyond possibility as yet—though not hopeless. Much of the knowledge that we need depends upon the discovery and elucidation of special geological conditions,— where peculiar surface features form a useful guide. This emphasizes the necessity of investigations in the field, both for scientific purposes and for the benefit and protection of the general public.

The following study—a consideration of earthquakes already recorded—is of use in giving direction to a search in the field for zones of earthquake genesis and for places that stand in special danger. In a small way the writer has proved this by work in the field, guided by this study.

I. INTRODUCTION

In the following work an endeavor is made to group and classify in a synthetic way the shocks of earthquake which have been recorded in California and the neighboring region. Practically all these have been brought together in catalogs published by Prof. E. S. Holden,[1] and by Prof. A. G. McAdie;[2] and in the Report of the State Earthquake Investigation Commission[3] on the earthquake of April 18, 1906, in which was given a supplementary list of shocks then recent.

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[1] Smithsonian Institution, Misc. Coll., No. 1087, 1898.

Professor Holden incorporated in his work all available records down to the end of 1896.

Of course it is certain that very many shocks have occurred in this region during the years these records cover which have found no place in these catalogs. It is almost sure, too, that some of these must be mentioned in scattered writings not available to Holden. However, search for these would require a vast amount of work which, at the very best, could yield only a small result. For no search could be made exhaustive with the archives scattered as at present; and the record during the whole period inevitably is incomplete because of the scant population and a prevailing want of interest in or understanding of the value attaching to careful and complete records of natural phenomena. Consequently sources other than the lists cited have been consulted rarely and only for special information. Further search for mention of shocks is deemed unprofitable for present purposes.

The shock in California in 1906 taught incontrovertibly that a great earthquake then originated along a zone of faulting at a time of renewed slipping over one another of the rock surfaces within and on opposite sides of the system of fault fractures. Such slipping is regarded as the cause of the earth-shaking, almost universally. The course of this fault is marked by a long narrow belt of peculiar surface features. Other similar belts are found. All of these are either known already, or are confidently expected, to demark zones of recent faulting. Undiscovered zones undoubtedly exist also.

It is the purpose of this study to inquire into the geographical location and circumstances of occurrence of the recorded shocks, and to set forth the close agreement which thus appears to obtain between the clustering of their places of origin and the courses of these long, narrow zones of known or suspected fault outcrop, referred to above. This appears to discover a reciprocal relation whose importance is emphasized below. Concurrently, the distribution of the shocks in the stream of time is exhibited.

In brief, all the recorded shocks are grouped and considered in reference to a hypothesis fully developed below.

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[2] Smithsonian Institution, Misc. Coll., No. 1721, 1907.

[3] Carnegie Institution of Washington, Publ. No. 87. Washington, 1908.

Although the following study is addressed primarily to students of seismic geology, it also should be of interest to the informed public in California. To render it intelligible to readers without instruction in geological science, it is desirable to take up certain elementary definitions and conceptions briefly.

On account of supposed differences in their *immediate* causes several types of earthquakes are commonly recognized, as follows:

(*a*) *Collapse* (or *Gravity) Earthquakes,* produced by *subsidence* or *collapse,* due to the falling in of the roofs or walls of caverns or the sudden closing up of any subterranean open spaces. In this category earthquakes due to the movement of great landslides are included.

Earthquakes of this sort are thought to be few in number and are generally considered to have little importance, because their energy usually is small and their origins shallow. Modifications of this type which may have large importance are still subjects of speculation or controversy.

(*b*) *Volcanic Earthquakes,* closely associated with the eruptive activity of volcanoes, though frequently distinct from actual eruption, considered to be due to violent gas or vapor explosions, or to sudden movements of the fluid magma in its cistern, with the accompanying rending and fissuring of overlying rock series.

(*c*) *Tectonic Earthquakes,* associated with differential movements in the rock crust of the earth, often of large magnitude extending over wide areas, inducing elastic strains which are relieved by fracture and faulting of the rock series, producing shocks of earthquake. The forces which bring about such crustal movements are imperfectly understood, but they frequently are of great magnitude and are active in the genesis and building of mountain systems, and in the uplift, depression or warping of great plateaus or continental areas.

In all these types the vibrations which produce earth-shaking are transmitted from the origin as a complex of wave motions controlled by the elasticity of the rigid earth matter. These are set up by successive elastic compression and rarefaction, and by oscillatory elastic distortion of form or figure—in other words, both longitudinal and transverse elastic wave-systems are generated simultaneously. These are transmitted in all directions through the solid earth, and over its surface.

When faulting takes place it is considered that these waves are generated, perhaps partly by the initial elastic excursions, or rebounds, of the rock particles at the instant of fracture, but probably in far greater part by elastic oscillations repeatedly produced by the blows which the sliding blocks of the earth's crust strike against each other during the brief time that movements of gliding and grinding are taking place along and within the system of fractures that divides the moving parts.

The foregoing classification of earthquakes has been employed very generally, but of late a considerable group of conservative students, chiefly geologists, have inclined toward the view that practically all earthquakes are of tectonic character. Whether this view is to prevail or not, general readers must understand clearly that the distinguishing causes cited above in any case are only the *immediate* causes. About the *ultimate* causes—the nature and mode of action of the forces which produce the fundamental stresses—our knowledge is slight. Various speculations about them are fascinating, but are without adequate test or check.

It is generally accepted that a great majority of shocks are tectonic in character. THOSE RECORDED IN CALIFORNIA HAVE UNDOUBTEDLY BEEN TECTONIC. For, except Mt. Lassen, we do not know in this region any recently active volcanoes which might be foci; nor have the shocks we know of been most frequent or most energetic near to the younger (or older) extinct cones. Here there appears to be no connection between the districts frequented by shocks and the places of more recent volcanic activity.

On the contrary, several of the more destructive shocks, like those of 1857, 1868, 1872 and 1906, were associated with (doubtless caused by) the slipping of faults. This association is known definitely. For in all cases the slip-fractures intersected the earth's surface in the district of strongest shaking. In 1906 most spectacular effects of shearing—sidelong horizontal off-sets in soil and vegetation, through buildings, across fences, roads, and so forth—were plainly to be seen all along a narrow belt, designated the *fault-trace,* which traversed Central California along a nearly straight course for a hundred and ninety miles and more—probably much more. Not only in California, but in New Zealand in 1848, in 1855, and in 1888, in Japan in 1891, and most strikingly in Alaska in 1899, as well as in many less conspicuous instances, powerful earthquakes have resulted from slipping along faults, producing a linear breach of the rock and soil surface. It is events like these that have led students of seismic geology to the opinion that most earthquakes, possibly all, are due to the slipping of faults. Since such slips must usually be of little magnitude, they do not commonly extend to the surface; and even when fairly large, often they do not become perceptible as offsets at the surface, because their differential movement may be distributed upward through divergent cracking and the compacting of deep loose soil, or surface layers.

With all this in mind even the most desultory reading of the catalogs of earthquakes in California is illumined by the suggestion—which gains greatly as study advances—that the districts of hardest shaking in many of the stronger shocks have been in close proximity to the San Andreas fault, where the 1906 shock unquestionably originated. This distribution of places of strong motion accords with the view that these earthquakes have been caused by slippings in this great rift. This raises the query, Do the places of high intensity in other cases fall into similar geographic groupings, lanes of foci of earth shock, and do these follow fault outcrops? Careful study strongly suggests an affirmative conclusion.

Besides the San Andreas rift, geological studies have discovered a considerable number of well-defined and extended faults in California, which traverse regions where many recorded earthquakes have originated. As study of the field goes on, still other faults will be discovered. Of those we know already, some, like the San Andreas fault, exhibit unquestionable evidence of repeated recent movements frequently breaching the surface; others, which have given no proof of recent activity, are by no means free of the suspicion of occasional slipping. But there are many which are very old. There is no suggestion in their present surface expression that these have been rejuvenated in late geological time.

Considering these known faults-zones as lines of reference, analysis of the occurrence and distribution of the earthquakes makes it clear at once that the San Andreas fault is not the only line along which seismic foci seem to cluster. Instead, a number of cluster lines claim attention which in most instances follow known faults. In some districts, however, epicentra appear to group in long narrow belts along which zones of faulting are not yet known.[4] Naturally it is thought probable that faults which are still subject to slipping may traverse such areas.

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[4] Since the following work of classification was completed the writer has found that at least two faults, marked by signs of recent pronounced slipping, traverse in its long direction a district whose axis is a cluster line, where no major fault was known at the beginning of this study.

We are led in this way to the hypothesis by which the following classifications are governed. This takes the form of a carefully restricted statement of the idea brought out immediately above, as follows:

In this classification it is assumed—

(a) that rock-slip movements along certain specified lines (either now known definitely to demark zones of faulting, or confidently expected to do so) have occasioned the earthquakes recorded in California;

and further, to make headway practicable in what at best can be only a crude approximation, it is assumed—

(b) that all the shocks recorded have originated on one or more of the specified lines—to the neglect of undiscovered cluster lines.

Here the writer desires to place great emphasis upon the point that this latter restriction, namely that only certain designated lines are assumed as seismic generatrices, is placed upon the hypothesis only to render it manageable in tabulating the inadequately recorded data now available.

The writer holds the opinion that with better and more complete records other active faults will be brought to light, and that such ambiguities and doubts as mar this present study will clear away from future endeavors.

The purpose here is merely to bring out clearly the suggestion that there is a causal association of earthquakes with fault zones in this region,—a relationship fraught with significance for human affairs.

On account of our present ignorance of the minutiae of the geology, and of the intimate behavior of the shocks, the results of this study are sure to be faulty in matters of detail. But the principle is considered sound,—and the method serviceable for a first approximation.

II. Methods of Classification

In order to classify the shocks recorded in this region in accordance with the working hypothesis employed in this study, it is convenient to divide them into two groups, according to intensity *as*

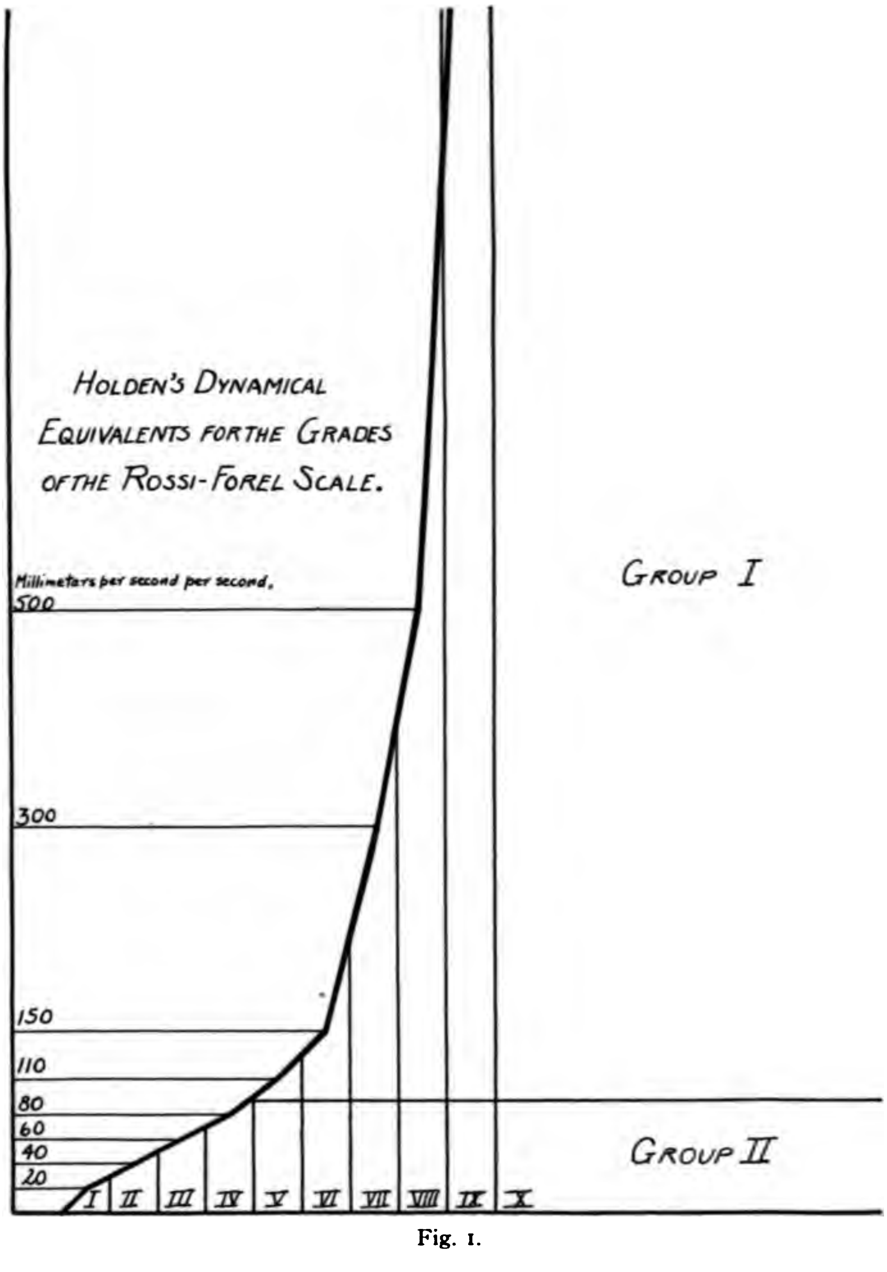
HOLDEN'S DYNAMICAL EQUIVALENTS FOR THE GRADES OF THE ROSSI-FOREL SCALE.
Millimeters per second per second.
500
300
150
110
80
60
40
20
I
II
III
IV
V
VI
VII
VIII
IX
X
GROUP I
GROUP II

Fig. 1.

defined by the Rossi-Forel scale—that used by Holden and McAdie in the catalogs.

Group I includes shocks which manifested an intensity of V or greater.

Group II comprises the weaker shocks, of intensity lower than V of the scale.

Such a division is not merely convenient, because there exists a substantial physical basis for it, and for choosing V of this scale as an approximate point of division. The intensity of an earthquake is proportional to the acceleration of the vibratory motion of the earth-particles—the rapidity and amount of their to-and-fro motion—depending upon the total energy of the shock. In the Rossi-Forel scale the total range of acceleration covered by the first four grades is small and the differences between the grades are very small. However, the total range of energy comprised under the upper four grades is very large, and increasingly large differences in acceleration distinguish grade from grade. Hence the region of energy defined by the fifth grade of the scale constitutes a sort of buffer state between the domains of two classes of earthquakes which differ markedly in character on account of pronounced differences in the rate and amount of their vibratory motions. Division exactly here is arbitrary, but hereabouts is a *natural* division point. So the line is drawn between the fourth and fifth grades. (See the diagram, Figure 1.)

Moreover, it is a view generally held by seismologists that earthquakes of the stronger sort (though in this connection the energy range may not be divided at an arbitrary point), result from rupture of the rigid rock due to strain accumulated beyond the strength of the material, or the regeneration of rupture in a cemented zone; while weaker shocks often are due to movements of settling and readjustment within a system of fractures already developed *and not re-cemented,*—the sources of strong shocks of no very distant date.

A further, practical reason for dividing the shocks into two groups is this—that in many cases *approximate* places of origin can be fixed with less uncertainty for the stronger shocks than for the weaker ones.

For this same practical reason—namely, the degree of certainty with which the places of origin can be estimated—two sub-groups are distinguished under Group I. Under sub-group A are assembled those shocks which were recorded in several localities, or in two localities distant from each other not less than twenty miles; and such shocks are designated by the letter A in the tables which follow. Similarly the letter B is employed to designate the shocks of Group I, sub-group B, which comprises those recorded in only one locality. Ordinarily the places of origin of shocks belonging to sub-group A can be estimated with more certainty than those of sub-group B.

The shocks included under Group II, of intensity lower than V of the Rossi-Forel scale, in a majority of cases have been recorded at only one locality, or in two or three closely neighboring places. Since the earthquake *records* we are dealing with were rarely made in isolated places like camps or ranches, but usually in settled communities, the location of which did not depend in any systematic sense upon the arrangement of earthquake generatrices, it would be difficult to fix upon the places of origin of these weaker shocks, even approximately, were it not for the guidance given by analogies with those of the stronger group. It is almost sure, however, that both weak shocks and strong emanate from the same sources, in California at any rate. Therefore it is legitimate to follow such analogy in *estimating* the position of origin of the weak shocks. Moreover, ONCE THE GENERATRICES ARE ACTUALLY DISCOVERED, then it is possible frequently to fix the place of origin of a weak shock with more certainty than that of a strong one,—because the region of high intensity of the latter may be large, and overlie several living fault zones, while that of the former will be small and must be situated immediately above a segment of its generatrix.

These two groups of earthquakes are tabulated separately.

In the first group the shocks are tabulated in chronological order in tables in which numbered vertical columns represent zones of known or suspected faulting, as discussed above and specifically described in the following chapter. In these tables the origination of each shock is ascribed to *every one* of these zones of causation which, in each particular case, can reasonably be considered a possible generatrix. This, of course, involves nearly every shock two or three to more times.

In carrying through this correlation, four degrees of probability are considered, and indicated in the tables by suitable symbols. Thus it is indicated that as the place of origin of a given shock a given fault is (*) sure or reasonably sure, (+) very probable or probable, (±) ambiguous, or (?) doubtful, according to circumstances and locality of occurrence or report.

The decision as to the degree of probability in every case is the personal judgment of the writer, guided by geographical and geological considerations in connection with the data of record.

In a second separate tabulation the weak shocks of Group II are treated in a precisely similar way.

Now it must be realized clearly that in following strictly this procedure, every one of the faults or lines *here considered* as generatrices has ascribed to it tentatively more of these shocks than have originated upon it in all likelihood. If this is not true of every fault, it is mathematically sure to be true of most. On the other hand, those shocks which are assigned to any fault with (*) sureness or reasonable sureness are certainly fewer than the number which must have emanated from it,—for usually such a fault must actually be a generatrix. It seems probable, too, that the sum of the shocks ascribed to it with (*) sureness or reasonable sureness, and with (+) much probability, is still a smaller number than the actual occurrence. So, in a very rough way, it is possible to set *lower* and *upper limits* to the number of these shocks which have emanated from a given locus suspected of seismic activity. Wherefore it is considered that any zone, which is characterized in this manner as the reasonably sure or very probable place of origin of many shocks, is surely a zone within which crustal movements still take place, the degree of activity being denoted roughly by the frequency of recurrence of the earthquakes.

Then, too, certain recognized zones of faulting, though indicated by this tabulation as the reasonably sure or probable loci of causation of shocks in very few instances only or not at all, nevertheless are thus marked out as the (±) ambiguous or (?) doubtful places of origin of many earthquakes. Consequently the possibility of slipping in the crust along these zones must not be lost sight of.

In some cases these traverse thinly peopled regions and so are correlated with meagre records, leaving their real activity greatly in doubt. In other instances they run parallel to prominent fault zones which are known to be still active, and are located so near to these that it is a very doubtful exercise of judgment, with present knowledge, to decide in the case of a given shock that its origin was in one of these zones of less certain *present* slipping rather than in its surely active neighbor. Some of these zones will be discussed in detail in another place.

Further, it will be seen that a few of the more prominent fault zones have very few shocks referred to them at all, and then always as ambiguous or doubtful places of causation. Obviously this suggests that earthquakes no longer emanate from these, or, at least, not definitely during the period of which we have knowledge. Some of these also will be discussed further on.

From a point of view of precise working such a method of study as is pursued here is frail; but it seems likely to bring out valuable ideas concerning the chief places of earthquake origin in California.

As a by-product, too, this correlation exhibits the way in which earthquake occurrence and intensity have varied in regard to *time* throughout certain important districts. It is recognized, however, that it may tend to conceal minor generatrices when these are located near to others that are surely active. Despite all its frailties, however, it seems to the writer a serviceable way in which to group and view the data.

Sources of Error

However, even the general reader will perceive the easy possibility of errors and misjudgments of much importance in such procedure; so a discussion of the possible sources of error properly finds place at this point.

No one can realize more clearly than the writer the opportunity for going astray in making decisions in particular instances when forming this correlation, and, consequently, in summing up the general conclusions. He has endeavored constantly to keep free of prejudice.

The chief recognized sources of error can be grouped in two classes:

(A) Errors arising from the incompleteness of available records.

1) Many shocks, possibly some strong ones, have not been recorded at all. Inevitably the record is deficient.

2) The catalogs are further incomplete in that they do not include all the information that the written record must contain.

3) Most of the shocks recorded must have been felt more widely than the available information declares.

4) The details concerning intensity, and so forth, given in the compilations, for the most part are inadequate for determining well either the degree or the geographical range of the intensity.

(B) Sources of error inherent in the formulation of the controlling hypothesis.

1) Spasmodic slipping upon geological fault-systems has been assumed as the sole cause of earthquakes in California, and *certain specifically designated fault zones, or zones of probable faulting,* are assumed (but for present purposes only) as the *only* probable places of causation of all the shocks.

Thus other possible causes of shocks are ignored; and so, in the tabulation, are ignored such possible loci of origin as undiscovered faults still in process of development; and known faults passed by for one or another of a variety of reasons stated for each particular case. This is an important and probable source of error. But, as an off-set for it, the study itself brings to light certain zones of earthquake causation along which faulting is not yet definitely known.

2) The likelihood of error in personal judgment in the interpretation of particular items of the record must in many instances amount to a certainty. So vague is the record frequently that it is extremely difficult to fix upon the more probable places of origin of many of the shocks with satisfactory definiteness.

In fairness to the correlation, however, it is to be pointed out that there is a tendency for such errors of judgment to cancel in the aggregate, unless conscious effort to avoid apparent inconsistencies is continually made. On the contrary, a serious effort has been made to judge each item individually and on its own merits.

Further, it is idle to hope that clerical errors in the correlation tables, and in the tables of summaries, have been eliminated completely, since only one worker has done all the checking and rechecking.

After the foregoing discussion, there is no need to dilate upon the probability of erroneous decisions finding place in the treatment which follows. In pioneering work upon a body of observations not made primarily for the purposes for which they are employed, mistakes must result inevitably. The broad conclusions should prove of service.

III. THE FAULTS OF THE REGION AS SEISMIC GENERATRICES

To summarize: Many faults have already been discovered in California and neighboring parts of the region; and it is known beyond question that several strong earthquakes have been associated with slipping in the zone of rupture of more than one of these. As before mentioned, these slippings have left their marks on the earth's surface—as long gashes rent through rock and soil and works of construction. Faults delineated in this way are indubitable generatrices of earthquakes, in even greater number than can be demonstrated from the records. There is little doubt that similar yieldings have taken place along the zones of other of the faults, but no unequivocal proof of this can be brought forward now. All these we must consider as seismic generatrices.

Some of the known faults are located in regions in which few people dwell; where, in consequence, but few earthquakes are recorded. This lack of records makes it practically impossible to discover, by such a correlation as is undertaken here, whether these faults are possible, or probable, loci of genesis of earthquakes.

Also, as mentioned above, some faults are very near, and closely parallel to, the major zones where frequent slipping occurs. Wherefore the association of recorded shocks with these faults as probable places of origin must involve ambiguity in any case—very often much doubt.

So in order to carry through this correlation practicably it is necessary to select with care those faults—which in other respects are to be regarded as possible zones of earthquake genesis—that traverse settled districts, so that the records will not be altogether inadequate for the purposes in hand.

Much preliminary study, and many trial tabulations and geographical groupings of shocks, led to the discussion and choice of the faults referred to in this chapter.

Our most recent and reliable synthesis of knowledge concerning the distribution and important faults in the California region is that delineated upon maps in the Atlas[5] of the Report of the 1906 earthquake. The general map of the series (Map No. 1), abridged and modified to meet present needs, is reproduced here as Plate I.[6] All

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[5] Atlas of Maps and Seismograms accompanying the Report of the State Earthquake Investigation upon the California Earthquake of April 18, 1906. Published by the Carnegie Institution of Washington, Washington, D. C., 1908.

[6] A valuable contribution to the delineation and nomenclature of faults in

APPROXIMATE GEOGRAPHIC CO-ORDINATES OF A LIST OF PLACES MENTIONED IN THE TEXT, BUT NOT PRINTED ON THE ACCOMPANYING MAP.

PLACES	APPROX. LAT.	APPROX. LONG.	REMARKS.
Amador Valley........	37°40'±	121°40'±	
Calico	34 55	116 55	
Carizo (Carrizo)......			Creek in Imperial county.
Daggett	34 50	117 00	
Dos Palmas...........	33 30	115 55	
Forest City	39 30	120 50	
Fort Point............	37 45+	122 30—	
Fort Klamath.........	42 40	121 58	
Georgetown	38 50	120 50	
Goodyear's Bar........	39 30	120 53	
Lake Merced..........	37 40+	122 30—	
Los Olivos............	34 40	120 05	
Mare Island...........	38 05	122 15+	
Minnesota			Sierra (Shasta?) county.
Nashville	38 40	120 50	
Newhall	34 20	118 35	
Oakdale	37 40	120 55	
Orleans Flat..........	(39 30)?	(120 50)	Humboldt (Nevada?) county.
Point Pinos...........	36 40—	121 55±	
Refugio			Santa Barbara county.
San Felipe............	37 00±	121 25	
San Fernando.........	34 20	118 35	
San Gregorio.........	37 25	122 20	
Santa Clara Valley, N..	37 30	122±	
" " " S..	34 20	119±	
Santa Isabel..........	33 08	116 40	
Wawona	37 35	119 40	
Keystone Ranch.......			Yuba county.

Southern California is found in an article by Carl H. Beal, "The Earthquake in the Imperial Valley, Cal., June 22, 1915," in *Bulletin of the Seismological Society of America*, 5, pp. 130-149, 1915. This article throws a good deal of light on the correlation in this part of the province—so that some changes have been made in this work on account of this new knowledge. The whole study, however, has not been revised, since that would entail great labor for small profit. And it must be borne in mind that the chief value of the present work does not depend upon its precision, but upon the guiding suggestions it brings to notice.

the faults selected from the following discussion are shown on this modified map, and unless otherwise indicated are referred to it. All the faults discussed (except one) are shown on the maps in the Atlas.

In discussing the faults shown upon the suite of maps cited, in order to make selections for use in this study, it is convenient to divide the region into three provinces:

(A) The Coast Mountain Province,
including both the Coast Ranges and the ranges of Southern California;
(B) The Great Valley Province; and
(C) The Sierra and Great Basin Province.

The first of these has been occupied longer by civilized men, and is much more generally and densely populated, so that our knowledge of its seismic history is far less incomplete. Consequently it is much the most important province in the whole region for the prosecution of this study.

THE FAULTS OF THE COAST MOUNTAIN PROVINCE

In the north among the Klamath Mountains seven faults are known, four of which are long. But all these traverse a region which has been almost uninhabited throughout much of the time over which our records extend; and it is still very thinly peopled. Few earthquakes have been recorded in this part of the province, and it is not warrantable to treat any of the faults known as their possible loci of origin, for no fault-slips have ever been observed here, and the data of report are far too meagre and vague to admit of any discrimination among the faults.

Near Punta Gorda, on the Mendocino coast, is encountered what is perhaps the most northern portion of the long San Andreas rift, upon which the 1906 earthquake originated. As is explained in the report[7] it is not sure that this most northern fault-segment is actually continuous with the rift further south, for a shallow indentation of the coast line interrupted the visible trace of the fault for many miles; yet the observed facts seemed not to admit of any definite alternative interpretation.[8] It is known definitely, however, that the San Andreas

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[7] Report San Francisco Earthquake Investigation Commission, 1. 48.

[8] Though as yet unable to bring forward conclusive proof of it, the writer,

rift extends as a continuous lane on to the southward, and then to the eastward, into the Colorado Desert, and very likely still further on,—except for three very short submarine (and therefore inferred) segments where in-sweeping curves in the coast line intercept it.

It is sure that the earthquakes of 1857 and 1906 were generated chiefly, if not solely, upon this fault, although upon different parts of its extent. Other strong shocks *seem* surely to have been caused by slipping in its zone. If so, it is obvious that many other shocks of suitable geographical distribution, may be correlated with it reasonably.

Since its length is so great—600 miles at the very least—it has proved convenient to consider this fault in four segments, thus more readily to show its relationships with neighboring faults in important districts. These segments have been divided off as follows:

San Andreas Rift:

(*a*) Punta Gorda-Point Arena segment (?),[9]
(*b*) Point Arena-San Juan segment,
(*c*) San Juan-Tejon segment,
(*d*) Tejon-Colorado segment.

This rift is the best attested and most important generatrix thus far discovered in the whole region.

About thirty miles from the coast, east of Fort Ross, the Mount St. Helena fault follows a NW.-SE. direction for more than twenty miles along the southwest base and flank of the mountain. Though it is not a very satisfactory procedure to correlate shocks definitely with this, nevertheless it is a possible locus of origin for them.

A fault at least twenty miles long runs in a N.NW. direction from the vicinity of Benicia, and lies along the base of the local Coast Range hills, where these emerge from the alluvium of the Great

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in consequence of extended work in the field of Mendocino county since the publication of the Report cited, now holds the opinion that this segment, seen in 1906 as a surface rupture near Punta Gorda, probably does not join with the San Andreas rift further south. However, awaiting proof of this opinion, he follows the published evidence and adopts the published view for employment here.

[9] This segment possibly may belong to another fault.

(*a*) Intercepted between east-west lines through Punta Gorda and Point Arena,
(*b*) " " " " " Point Arena and San Juan Bautista,
(*c*) " " " " " San Juan Bautista and Fort Tejon,
(*d*) " " " " " Fort Tejon and the Colorado Desert.

Valley. In this paper this fault will be called the Suisun fault. It is possibly a seismic generatrix.

The Haywards fault stretches southeastwardly from San Pablo Bay along the western margin of the hills east of Berkeley and on for a distance of fifty miles surely, possibly for one hundred miles or more. It is probable that it may extend northwestwardly beyond San Pablo Bay also.[10] Its complete extent has not been worked out. The strong earthquake of 1868 indubitably originated, in part at least, with a slip movement in the zone of this fault. It is quite a certainty that many other shocks have been generated upon it. It is, therefore, an important generatrix, possibly the second in importance in the Coast Province.

A fault system, apparently complicated, runs roughly parallel to the Haywards fault on the eastward of it, extending from Martinez on Carquinez Straits to near Mt. Hamilton, a distance of at least sixty miles—possibly much more. This has been referred to as the Sunol fault, and by other names. The most northwestern branch of it has been called the Franklin fault. Here we will call it the Sunol fault-system.

The meizoseismal area of the shock of July 3, 1861, was in Amador Valley, adjacent to this fault-system. At that time a long crack was noted extending along the base of the hills on the western side of the trough which separates the Mount Diablo Range from the Berkeley hills and their eastern outliers thereabouts. This fault-system, then, is undoubtedly a generatrix. However, owing to its proximity to, and its parallelism with, the Haywards fault it is a difficult task, usually unsatisfactory, to attempt to discriminate between these in designating the places of origin of many of the recorded shocks.

Similarly it is difficult to make discriminating decisions involving a short fault which extends from the vicinity of Niles to near Mt. Hamilton,—thus located between the Haywards and the Sunol faults and roughly parallel with them.

It is desirable to point out that this fault may have been concerned with the generation of the earthquake of 1839. Holden quotes a manuscript note by Bancroft as follows: " . . . and one immense fissure extended from Lone Mountain (?) to Mission San Jose."

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[10] Since this study reached a very advanced stage, work in the field conducted by the writer in Sonoma and Mendocino counties, northwestward from the San Pablo Bay terminus of this fault, has brought to light abundant evidence of youthful fault-trace phenomena lying in line along a natural extension of the Haywards fault in this direction. These features undoubtedly extend many miles northwest from San Pablo Bay. Their course has not yet been completely delineated.

The writer has been unable to identify the mountain thus referred to as "Lone Mountain." The statement suggests strongly that a fault-trace was developed by the slipping which produced this shock; and if the mountain referred to as Lone Mountain were possibly Mt. Hamilton, then the fissure would approximate closely to the course of this fault. However, if we take into account the date, and the paucity of place-names then in current use, we may reasonably construe the statement to describe a fault-trace developed on the Haywards fault. Geologically this is the more likely construction. Hence no name is given here to this fault, and in the classification it is disregarded.

On the San Francisco peninsula a fault very feebly expressed in the forms of the present land surface stretches for a very short distance in a southeast direction from the vicinity of Fort Point, a minor promontory on the south shore of the straits of the Golden Gate. Probably dislocations no longer take place on this fault. It must be disregarded in this correlation.

The San Bruno fault, more important than the preceding, cuts completely across the San Francisco peninsula in a southeast direction from a point on the coast about four miles south of the Golden Gate. Despite a great vertical displacement along this fault, still expressed boldly in the surface configuration, the epicentra of recorded earthquakes show no tendency to cluster along its course. There is a possible exception to this statement in the case of a shock which occurred on November 22, or November 24 (?), 1852. This occurrence is discussed in detail below. The fault otherwise is disregarded in this study.

Two relatively old and minor faults, the Fifield fault and the Pilarcitos fault, occur on the San Francisco peninsula a little to the west of the San Andreas fault. These run roughly parallel with it; and both intersect the coast line north of San Pablo Point. No apparent relationships of these with any recorded shocks have been discerned. They are not considered in the correlation.

The San Gregorio fault stretches southeastwardly from a point on the coast west of San Gregorio until it again meets the coast line near Point Año Nuevo. It is not improbable that it actually extends considerably further in both directions. Its known extent is less than twenty miles. Its association with earthquakes is doubtful, but *possibly* it is a fault from which shocks occasionally emanate.

Lying between the San Gregorio fault on the west and the San Andreas rift on the east are faults named as follows: The Castle Rock fault, the Butano fault, the White Rock fault, the Boulder Creek fault, and the Zayante fault. These all have courses approximately NW.-SE. They are shown on Map 22 of the Atlas of the Report on the 1906 earthquake already cited.[3] Probably these are all of minor importance, and they are not further considered in relation to the present data of observation. The Boulder Creek fault, however, is so significant a feature of the land topography as to make it a line of importance in the digestion of future records of more detailed character.

Just north of the foregoing group of faults is a short fault, also of minor importance, known as the Black Mountain fault. This appears to branch off, like a short spur, from the San Andreas fault, running in an east-southeast direction. The available records make no suggestion that earthquakes emanate from it.

In regard to a considerable number of shocks felt chiefly in the vicinity of Monterey Bay, the records suggest a place of origin at sea. Of course no definte verification of this can be established in the case of past shocks. Nor can the course of any submarine zone of faulting here be delineated, except hypothetically. The line drawn on the accompanying map is intended merely to visualize this suggestion. The probability of such a zone is recognized, and therefore a Monterey submarine fault-zone has been considered among the loci of genesis for shocks on record.

Near where the Pajaro River intersects the San Andreas fault is a short cross-fault, known to extend for a distance of less than fifteen miles in an E.NE.-W.SW. direction, stretching a little way either side of the San Andreas zone. It is probable that it extends farther than is now definitely determined. It lies approximately along the axis of the Monterey Bay syncline, and its downthrow is to the north. Although definite proof is wanting, and though it is difficult to correlate shocks with it with confidence owing to its proximity to the active San Andreas zone, nevertheless it is quite possible that certain shocks have been caused by slipping on this fault. In this study it is named the Pajaro fault.

A fault more than ninety miles long traverses the Salinas Valley in a NW.-SE. direction. This runs along the eastern base of the

Santa Lucia Range and bears the name, the Santa Lucia fault. The recorded earthquakes do not indicate with any force that this fault has been concerned in their causation; but the trial correlations do not warrant neglecting it altogether in this study.

A fault not shown on any map has been recognized [11] as running parallel with the general trend of the coast for a short distance southward from the vicinity of Point Sur. There is no knowledge of earthquake epicentra associated with this fault; and it is neglected here.

West of the Santa Lucia fault near its southern end is a short fault parallel with it, stretching some twenty miles or more southeastward from the town of Lockwood. Study of the record of shocks does not encourage the opinion that this fault is among the active loci of causation of earthquakes here. So it is neglected in this correlation.

A fault about forty-five miles long extends southeastwardly from the vicinity of Paso Robles and Templeton, parallel with the mountain trend. While the areas of strong intensity of earthquakes felt in this region do not, in an unequivocal way, tend to cluster along this line, still the data for this region are not free from ambiguity, and it is possible that movements occasionally do occur within the zone. In this paper the fault is referred to as the Templeton fault, since the writer knows no name hitherto given to it.

West of all these is a fault more than a hundred miles in length, which runs southeastwardly, parallel with the San Andreas rift, from near San Simeon to the drainage of the Santa Ynez River. This fault will here be called the San Luis Obispo fault, since the district it traverses lies chiefly within the county of that name. It seems likely that certain earthquakes have been caused wholly, or in part, by movements within this fault.

An east-west fault more than sixty miles long is shown traversing the length of the Santa Ynez Valley. It is named here the Santa Ynez fault. This was not mentioned by Arnold in his description of the region.[12] However, earthquakes occasionally originate in this district. Possibly there are other important faults unrecognized here. In the present state of knowledge it seems best to accept tentatively the Santa Ynez fault as shown, and to regard it as a probable generatrix of earthquakes. Without doubt some such generatrix—possibly more than one—traverses this district.

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[11] Verbal communication to the writer from Prof. A. C. Lawson.

[12] Bulletin U. S. G. S., No. 322.

Running eastward from the coast near Ventura until it intercepts the San Andreas fault a little north of San Bernardino, is the San Gabriel fault. This traces a slightly curved path more than a hundred and ten miles long. Although all through this part of the province the data lead to ambiguous opinions, there are many shocks whose places of origin may be located along this zone with much probability.

An east-west fault about thirty miles in length marks the southern base of the Santa Monica Mountains. This is designated here by the name, the Santa Monica fault. Though epicentra do not cluster along this fault conspicuously, yet it cannot be neglected in this classification.

A similar statement applies to a short fault extending E.SE. from near Los Angeles, here called the Whittier fault.

Certain shocks felt at points along the southern coast between the Santa Barbara region and the San Diego region seem surely to have been generated at sea. A submarine fault is known just east of San Clemente Island; but it is not warrantable to assign these shocks to this fault definitely, for it is too distant to be the *probable* source of them. Nor would the vague information recorded justify such assignments even if the fault were nearer the coast. However, no other submarine fault is known definitely off this shore. Consequently a vague term, the San Pedro Submarine fault-zone, is employed to designate a submarine generatrix whose location and extent cannot be delineated even approximately. The line shown on the accompanying map is purely hypothetical, and is intended merely to visualize the suggestion.

A fault parallel with the coast line and very near to it extends for a distance of more than twenty-five miles from the vicinity of Capistrano directly toward Escondido. This is called the Santa Ana fault in this paper; and it cannot be omitted from consideration here, though it is dubious whether it actually is a place of genesis of any earthquakes so far recorded.

If the data do not mislead greatly, the Elsinore fault probably is an important source of shocks. This extends southeastwardly in a practically straight line along the eastern base of the Santa Ana Mountains from near Pomona to the Santa Margarita River *at least* a distance of more than fifty miles. It almost certainly continues southward,—though a short segment is unproved,—following the course of a fault shown running southeastward from the Santa Margarita drainage. Beal[13] is inclined to extend it at least to the Mexican boundary near 116° W. Longitude, and possibly far into Lower California. This southern extension passes through an almost uninhabited district, from which very few records have been derived. As a whole, however, the fault surely deserves attention in this correlation.

East of this and parallel with it is the Agua Caliente fault, trending southeastwardly, probably into Lower California, from a point east of Elsinore Lake. Probably future study will bring to light evidence of activity upon this fault; but it passes through a district almost unoccupied hitherto, and it is inexpedient to correlate it with the records in hand.

The San Jacinto fault is an important zone of crust dislocation extending southeastwardly along the western front of the San Jacinto Mountains, probably well into Lower California, a distance of at least two hundred miles. This probably intercepts, or branches from, the San Andreas rift northwest of San Bernardino. Beal[14] gives evidence tending to show that it crosses the San Bernardino Valley. Indeed, it is not impossible that this may be one of the chief continuations of the great crust-fracture system to which the name, the San Andreas rift, has been given; but such a suggestion needs thorough investigation before it can be accepted even tentatively. Slips undoubtedly have occurred on this fault several times in recent years. For example, the strong shock of June 22, 1915, originated in its zone at a center near the Mexican boundary.

Parallel with the San Jacinto fault, and a little south of it, is shown a fault which may slip yet from time to time; but this passes through a district which has been almost uninhabited, where, accordingly, few shocks have ever been recorded. For this reason it finds no place in the tables which follow. Another fault runs south-southeastwardly into Lower California, beginning near the southern end of the foregoing. This also traverses an uninhabited region, and cannot be included in the tables. When it is necessary to refer to these faults in the special discussions they will be called the north, and south, Carizo faults, respectively. Eventually they may find distinctive names.

Just a little northeast of the southern end of the San Andreas fault, as this at present is delineated, is a fault known as the Mission

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[13] *Bulletin Seismological Society of America*, 5, 135-136.

[14] Ibid., 5, 136.

Creek fault. It traverses a scantily peopled district, and is not considered further here.

North of the San Bernardino Mountains is a curving fault which traverses a desert region, and hence is of no importance for the present purpose.

Two short faults, probably of minor importance, are shown to the south of the San Andreas fault near Palmdale; and a third, not far away, traverses a portion of the San Gabriel Range. With our present information these cannot be considered in this study.

The records show conclusively that a large number of strong shocks have been felt chiefly in districts situated in a long narrow region extending in a general way from Eureka, on the north coast, to San Pablo Bay, near the coast in Central California, including districts neighboring to Ukiah, Cloverdale, Santa Rosa and Sonoma. The suggestion is obvious that the places of origin of these shocks also have been situated at intervals along this linear region, and hence that a fault or a group of faults, as yet not discovered,[15] traverses this region approximately along this line. In this connection it is pertinent to point out that the Haywards fault runs southeast from San Pablo Bay along a course practically continuous with this line, and that the Haywards fault has been *known* to slip more than once during the years considered here, producing violent shocks of earthquake. The northwestward continuation of this fault zone is probable. But since no such faulting is definitely known in this linear district, it is here considered merely a locus of shock origins,—designated by the name, the Eureka-Ukiah-San Pablo Line; and in the tables which follow it is treated jointly with the recognized faults as a generatrix of earthquakes.

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[15] Since the above was written, and the tables which follow were constructed, field study by the writer has demonstrated that topographic peculiarities characteristic of living faults do mark a continuation of the line of the Haywards fault northwestwardly far into this long linear region—how far is not yet fully determined. Moreover, similar indications of at least one additional living fault have been discovered in this region, with still others probable. These findings tend to confirm the hypothesis employed here; but since the number of such faults is not yet known, nor the courses mapped, it has not seemed worth while to the writer, in the present paper, to discard the general Eureka-Ukiah-San Pablo line simply to undertake the large and difficult task of *re-assigning ambiguously* all the shocks here correlated with this line. But it is a source of gratification that indications of this group of faults were readily brought to light when search was made where their existence was so forcefully indicated.

THE PROVINCE OF THE GREAT VALLEY OF CALIFORNIA

Few faults are known definitely within this province,—perhaps none at all if its boundaries are delimited very strictly. But there are certain zones along its eastern margin which cannot be dismissed without comment.

At the northern end of the Valley, to the east of Tehama, there is a long fault of slight curvature, concave to the east, which extends from a point about ten miles east of Anderson south-southeastwardly to a point a like distance east of Chico,—a stretch of about sixty miles. The age of this fault and its physiographic expression are not known to the writer. But the scant and very indefinite record of shocks in this district does not permit its being considered here as an active generatrix of earthquakes.

There are two short faults in the foothill country to the east of the zone just mentioned; but, for like reasons, these have no importance for the purposes of this study.

In the south part of the province, just at the base of the foothills of the Sierra, is a fault-zone about forty miles in length which extends north and south between a point about twenty miles southeast of Porterville and a point about ten miles east of Bakersfield. But once again the records are too scant and too indefinite in character to serve as a basis for any conclusions in regard to the activity of this fault.

The faults above mentioned include all that are shown belonging within the province of the Great Valley, even if its boundaries are extended liberally. No reasons appear for considering that earthquakes emanate from any of these. Yet there are records of earthquakes whose places of origin appear to have been located within this region. Hence in order to visualize the distribution of these shocks geographically, and in regard to time, it has seemed practicable and desirable to correlate them with an arbitrary geographical line, drawn southeastwardly from north of Shasta City to Tehachapi. For convenience in making comparisons this line is divided into two segments,—the Shasta-Stockton segment, and the Stockton-Tehachapi segment,—of the Great Valley axis. *This line* is not considered to delineate, even crudely, any fault zone or chain of faults,—simply to bring to notice the tendency for certain meizoseismal areas to cluster in line along the Valley.

FAULTS AND LINES TENTATIVELY CONSIDERED AS GENERATRICES OF EARTHQUAKES

COAST MOUNTAIN PROVINCE	GREAT VALLEY PROVINCE	PROVINCE OF THE SIERRA AND GREAT BASIN
1. SAN ANDREAS FAULT	11. Great Valley axis	Klamath Lake fault
(*a*) PUNTA GORDA–POINT ARENA SEGMENT	(*a*) Shasta–Stockton segment	Warren Mountains fault
2. EUREKA–UKIAH–SAN PABLO LINE		12. Honey Lake fault-zone.
1. SAN ANDREAS FAULT		13. MAJOR SIERRA FAULT-SYSTEM
(*b*) POINT ARENA–SAN JUAN SEGMENT		(*a*) BECKWITH–MONO SEGMENT
3. Mount St. Helena fault		
4. Suisun fault		
5. MARE ISLAND–NEVADA–CARSON LINE		
6. HAYWARDS FAULT		Bodie fault
7. Sunol fault-system		
8. San Gregorio fault		
9. MONTEREY SUBMARINE FAULT-ZONE		
10. Pajaro fault		
1. SAN ANDREAS FAULT	11. Great Valley axis	13. MAJOR SIERRA FAULT-SYSTEM
(*c*) SAN JUAN–TEJON SEGMENT	(*b*) Stockton–Tehachapi segment	(*b*) MONO–TEJON SEGMENT
14. Santa Lucia fault		
Lockwood fault		
15. Templeton fault		
16. San Luis Obispo fault		17. Kern fault
1. SAN ANDREAS FAULT		
(*d*) TEJON–COLORADO SEGMENT		
18. Santa Ynez fault		
19. San Gabriel fault		
20. Santa Monica fault		
21. SAN PEDRO SUBMARINE FAULT-ZONE		
22. Whittier fault		
23. Santa Ana fault		
24. ELSINORE FAULT		
Agua Caliente fault		
North, and South, Carizo faults		
25. SAN JACINTO FAULT		

hood of Nevada City in the foothills of the Sierra, and on in a curving line to the vicinity of Carson City in Nevada. This zone, ill-defined but relatively narrow, stretches across all three of the provinces considered here, and cannot be regarded as belonging to either alone. This zone or line has no significant expression in the forms of the land surface, and it is not known to coincide with, or to lie neighboring to, any fault or chain of faults or recognized flexure in the rock crust. Nevertheless the earthquake records point out in no uncertain way that the places of genesis of a considerable number of important shocks are very closely associated with this elongate district or line. The cause of this association awaits discovery. Of course a deep-seated locus of faulting, possibly incipient, is suggested. Such a suggestion is one of the points in favor of a crude study of the present sort.

It is worthy of remark that the summits of the southern Sierra are conspicuously higher than those of the northern Sierra, and the two groups of high summits are separated by a conspicuously lower summit area. The southern summits appear to be growing in height faster. This differential uplift, if real, may be distributed over a long flexure; or it may be concentrated in a sharp flexure with local fracture and faulting, breaking the back of the range. Such action, or more definite deep faulting, may afford an explanation of this seismic tract.

It is worthy of notice, too, that the lines of equal anomaly of gravity as determined by the free-air method of reduction [16]—in the computation of which the effects of topography and its isostatic compensation are neglected—are closely spaced, parallel, straight lines extending from the neighborhood of San Francisco Bay to that of Carson City. This arrangement is not shown when other methods of reduction are utilized which take account wholly or in part of the topographical and isostatic conditions. A causal association of tracts of rapidly varying anomalies of gravity with systems of faulting has been discussed; [17] but the rationale of the association has not been worked out thoroughly, and anomalies of gravity are subject to different interpretations. Nevertheless, the striking correspondence pointed out here is of interest in this study.

In referring to this cluster-line in the following tables it will be called the Mare Island-Nevada-Carson line.

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[16] "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity," (second paper), by William Bowie; Spec. Publ., No. 12, U. S. C. & G. S.

[17] Hobbs, "Earthquakes," 298-310, and refs. New York, 1907.

In the list on page 82 a summary is presented of those faults and lines, tentatively considered as generatrices of earthquakes in this California region, which have been mentioned, or briefly discussed, in the foregoing pages.

This list is geographical in scheme, reading vertically from north at the top to south at the bottom, and from west at the left to east at the right. Hence in the left-hand column are the faults which pertain to the Coast Mountain province, while those in the right-hand column pertain to the province of the Sierra and Great Basin.

The numbers which are given to these faults in this list are those used to designate them in the correlation tables which follow. Those which are not numbered are not found in the tables, but they are sometimes referred to in the special discussions of certain shocks included below.

IV. Systematic Tabulated Correlation of Earthquakes with Known or Suspected Generatrices: Discussion for Particular Shocks.

Shocks of Group I.
Sub-groups A and B.
Table I: Discussion.

(*All* shocks prior to 1850 are placed in Group I, regardless of estimated intensity, on the assumption that very few weak shocks were recorded during earlier years, so scant is the record.)

In Table I two categories of the stronger earthquakes recorded in the catalogs are segregated and combined in one group, arranged in chronological order and correlated with the principal faults and lines discussed above. These two categories are differentiated here by the letters A and B.

Shocks designated by the letter A have been felt and recorded at two or more localities distant from each other by not less than twenty miles; and all such shocks entered in the catalogs are included in this group. So far as it is now posible to judge, a great majority of these shocks have manifested an intensity of V, or greater, according to the Rossi-Forel scale.

Shocks designated by the letter B comprise all earthquakes which Holden, McAdie and others considered to have manifested an intensity of V, or greater, according to the Rossi-Forel scale, at one locality only (or in one small neighborhood). Owing to the relatively high intensity of these shocks, taking account of the known imperfection of the records, it seems certain that all, or nearly all, of them in reality must have affected a much larger district than the extant accounts of them specify. These shocks probably do not differ in the matter of actual occurrence, or genesis, from the shocks of sub-group A,—the difference consisting almost wholly in the record.

Therefore both sub-groups are conjoined in the table and in the special discussions which follow it.

Table I.

The table is constructed in the following way:

The first column at the left-hand contains the letters A and B which designate the sub-groups to which the shocks belong.

The second and third columns exhibit estimates of intensity, by the writer and by the catalogers respectively. In most instances the intensity given in the catalogs is not estimated for the shock as a whole, or in its epifocal tract, but rather at the places of report. In many such instances examination of the distribution of strong effects leads conclusively to a higher estimate for the epifocal maximum than that at any of the places of report.

In seismology, knowledge has advanced rapidly in recent years. Upon further scrutiny in the light of this development, in certain instances estimates which presumably referred to the maximum intensity now appear too low: so the writer has revised them. In this group there may be cases of doubt, but the later decision will be sustained by critical students in almost all cases. In this connection the imperfection of the reports, and the Italian origin of the scale, must be remembered.

In the fourth and fifth columns are shown the year, and the month and day, of the shocks tabulated.

Many of these events have been multiple. In the sixth column, numbers, or vaguer estimates, are given to indicate the occurrence of earthquakes on the dates opposite which they appear.

The remaining columns are numbered to correspond with faults and lines discussed above.

The arrangement of these numbered columns exhibits a geographical property. To some this will be the most interesting feature of the study. It may prove to be the most valuable intrinsically.

Thus:—

1*a* and 2 traverse the northern coast region.

2, 1*b*, 3 to 10 are lines that are associated with the central coast region (except that 5 extends transversely across the entire state).

12 and 13*a* lie along the northern part of the eastern flank of the mass of the Sierra.

11*a* extends along the Great Valley between the two foregoing groups.

1*c*, 14, 15 and 16 traverse the south-central coast region.

13*b* and 17 are associated with the southern part of the eastern flank of the Sierran block.

11*b* traverses the Great Valley between the two foregoing groups.

1*d* and 18 to 25 are associated with the south coast and mountain region.

In the tabulation these geographical sub-groups are marked off by vertical lines. Also a vertical line has been drawn between 6 and 7, and on both sides of 21, simply for convenience in tabulation and reading.

Though this geographical property of the correlation is sounder intrinsically than the effort definitely to locate shocks upon their generatrices, it certainly is less instructive, and the writer thinks it far less fruitful in suggesting the direction future field and laboratory study should take. The ultimate determination of all generatrices, and routine observation of their behavior, is the social and economic goal of seismology here. It is also an important scientific desideratum. The merely geographical property of the correlation, while less likely to error, is not constructive.

However, the geographical results are summarized later, as well as the data in regard to generatrices.

[N. B.—The events marked with the symbol §, are those considered in the special discussions which follow Table I.]

TABLE I.—TABULATION OF EARTHQUAKES WITH KNOWN OR SUSPECTED GENERATRICES.

Sub-Groups	Intensity		Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
B		..	1769	April 11		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	±	?
A	VIII-X	VI?	"	July 28	4+ many	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	?	+	?	.	±	±
B		..	1770			§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	±	±	.	.	±	±
A		X	1790?			§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
B		..	1800	Oct. 11-18-31	Many	§	.	.	.	+	.	.	.	±	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		..	"	Nov. 22		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		..	1803	April		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	±	±	.	.	±	±
B		VIII	"	May 25		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	±	?
B		VIII	1806	March 24		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	+	.	+	.	.	.	.
B		VIII	1808	June 21-July 17	18	§	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII+	1812	May, 4½ mos.	Many	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	?	±	?	+	?	?	±	±
A	X	IX	"	Sep., Oct. or Dec.	Hundreds	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	?	±	?	+	?	?	±	±
B	[IX-X]?	..	"	....		§	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX	1813?	....		§	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			1815?																																		
B		...	1815	Jan. 18	5	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	?	.	+	.	.	.	.
B			"	Jan. 30	2+	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	?	.	+	.	.	.	.
B			"	July 8-9	6	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	?	.	+	.	.	.	.
B		VIII	1818	....		§	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...	1821	Jan. 1		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	?	+	.	?	?	.
..			1824			.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	VIII?	...	1829	Sept.	Several	§	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VIII	1830			§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	±	.	.	.	.	.	.	.	.	.	.	.	.
B		....	1836	April 25		§	.	.	.	±	.	.	.	±	.	?	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X?	VIII	"	June 9-10+	Many	§	.	.	.	±	.	.	.	+	.	?	?	?	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII	1838	June-July	Shocks	§	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX	1839	....	Many	§	.	.	.	?	.	.	.	•	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	X?	IX	1840	Jan. 16-18		§	.	.	.	±	.	.	.	?	.	±	+	?	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII	1841	July 3		§	.	.	.	±	.	.	.	?	.	?	+	?	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		III	"	Summer	120+	§	.	.	.	±	.	.	.	?	.	?	±	?	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII?(+)?	1843	June 23		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	.	.	.	?	±
B		III	1848	Jan. 4		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	±	.	?	.	.	±	?
B		...	1849	Sept. 16		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	+
B		...	1849	Sept. 22		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	+

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		...	1850	May 13	(6)	.	.	.	.	±	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Aug. 4		.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.
A		...		Aug. 15		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	±
A		V		Sept. 14		.	.	.	.	±	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...	1851	May 13		.	.	.	.	±	.	.	.	±	.	?	?	.	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VIII		May 15	3	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		III		May 28		.	.	.	.	±	.	.	.	?	.	?	?	.	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		June 13		§	.	.	.	?	.	.	.	?	.	.	.	.	.	.	.	?	.	?	?	.	.	.	?	?	?	.	.	.	.	.	.
B		V		Nov. 12		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		Nov. 13		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Nov. 26	11	§	.	±	±	+	.	.	.	±	.	?	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		Dec. 2		.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		Dec. 26	3	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 31		.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
[B		...		Dec. 31	3	.	.	.	.	±	.	.	.	±]?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...	1852	April 12		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	±	?
A	X?	...		Oct. 26	11+	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	±	.	.	.	+	?	?	.	.	.	.	.	±
A	X	VIII-IX?		Nov. 9	Hundreds	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	+
B		VIII		Nov. 22		§	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
[B		...		Nov. 24		§	.	.	.	+	.	.	.	±]?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
[A		...		Nov. 26?	11+	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	±	.	.	.	+	?	?	.	.	.	.	.	±]?
A	X	IX		Nov. 27-30	Many	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	±	.	.	.	+	?	?	.	.	.	.	.	±
A		IX		Nov. 29		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	?	±
B		...		Dec. 5		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	±
B		V		Dec. 17		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	?	.	.	.	.	.	.	.	.	.	.	.	.
A		IV	1853	Jan. 2		§	±	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	IX?	VIII		Feb. 1		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.
A		V		Mar. 1		§	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	?	.	?	?	.	.	.	.	?	?	.	.	.	.	.	.
A		"Smart"		June 2	2	.	.	.	.	?	.	.	.	.	.	.	.	?	.	.	.	?	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.
A		...		Sept. 2? 3?	4	§	.	.	.	?	.	.	.	.	.	.	.	±	.	.	.	?	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.
B	IX-X?	VIII		Oct. 23	3	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX?	...		Dec.	Many	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	±
A		V	1854	Jan. 3	2	§	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.
B		V		May 3	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	±	±	±	.	±	.	.	.	.
A		VI		Oct. 21		.	.	.	.	±	.	.	.	±	.	?	?	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Oct. 26	Shocks	.	.	.	.	±	.	?	?	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V	1855	Jan. 13		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	?	?	?	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		V	1855	Jan. 14		§	±	?	?	+	.	.	.	±	.	.	?	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Quite severe"		Jan. 24		§	.	.	.	.	.	.	?	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		III		April 7		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		June 25		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	+	?	.	.	.	.	.	.
A	IX?	VIII		July 10	4	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	±	?	+	.	.	±	.
A		...		Aug. 26		.	.	.	±	?	±	?	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Aug. 27		.	.	.	±	?	±	?	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 21		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		III-IV?		Oct. 27		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Dec. 11		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII	1856	Jan. 2		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Jan. 10		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	?	±	.	.	±	±
B		V		Jan. 21		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Jan. 28		.	.	.	±	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII		Feb. 15	3	.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		April 6		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	±	?	.	.	±	±
B		V		May 2		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	±	?	.	.	±	±
A		III and IV?		Aug. 2		.	.	.	.	.	.	.	?	?	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		Aug. 27	2	.	.	.	.	±	.	.	.	?	.	.	+	.	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Sept. 6		.	.	.	.	±	.	.	.	±	.	.	+	?	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII		Sept. 20		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	±	±
A		...		Sept 25		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	±	±
A	X	IX	[?]	"In the fall"		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
B		V	1856	Nov. 12	2?	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	±	±
B		VII	[?]	Dec. ?		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX	1857	Jan. 8-9	Hundreds	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	●	.	±	.	±	.	.	?	±
B		V		Jan. 16		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	.	±	.	.	?	±
A		VI		Jan. 20		.	.	.	.	+	.	.	.	?	.	.	.	.	.	.	.	●	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.
B		V		Jan. 21		.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.
A		...		Feb. 5	2 Shocks	.	.	.	.	±	.	.	.	±	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		March 14		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	±	?	±	.	.	.	.
B		VI		April 1		.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		April 24		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		May 3		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	±	?	.	.	±	±
A		VI		May 23	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.
B		VI		June 14		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		July 5		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
B		V	1857	August 8		.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		August 29		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
A	V±	III		Sept. 2		.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Oct. 19		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		III		Oct. 20	3	.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Nov. 8		.	.	.	±	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V	1858	Feb. 10		.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Feb. 15		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Aug. 18	2	.	.	.	±	±	●	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Sept. 2		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	●	±	±	●	±	.	.	.	.
A		V		Sept. 3		.	.	.	.	±	.	.	.	±	.	●	●	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Sept. 12		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX?	VIII		Nov. 26	2	§	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI	1859	Jan. 25		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		March 25	14	§	.	.	.	±	.	.	.	+	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		April 4		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Aug. 10		.	.	.	.	±	.	.	.	+	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV?		Sept. 9	2	.	.	.	±	±	●	.	●	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Sept. 22		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Sept. 26		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII		Oct. 5		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Dec. 1		.	.	.	.	±	.	.	●	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 1	Several	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	●	.	.	.	.	.	±
B		V		Dec. 11		.	.	.	.	±	.	.	.	±	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X?	VII	1860	March 15		.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		March 26		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	●	●	●	●	.	●	●
A		VI		March 27		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	●	●	●	●	.	●	●
B		VI		April 2		.	.	.	.	+	.	.	.	±	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		April 16	2 Shocks	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	±	●	●	.	±	.	.	.	.
B		VI		April 16		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Sept. 23		.	.	.	.	.	.	±	±	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Nov. 12		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI	1861	Jan. 12	2	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		March 23		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		April 29		.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X?	IX?		July 3-4	Many	§	.	.	.	.	.	.	.	●	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Violent"		Sept. 16		.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	Intensity		Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	2	25
	Wood	Holden																																			
A		VI	1862	May 27	Many	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	●	±	±
B		VI		July 2		.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Sept. 20		.	.	.	±	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Oct. 21	(7)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	●	±	±
B		V		Dec. 23		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI	1863	Jan. 25		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	●	±	±
B		VI		Jan. 25		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	●	±	±
B		V?		Feb. 1		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		March 18		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		June ..		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		July 15	2	.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		July 15		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		July 24		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Strong"		July 31		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Aug. 2	3	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII?		Dec. 19	2	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Dec. 23		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 30	Several Shocks	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI	1864	Feb. 26		§	.	.	.	±	.	.	.	±	.	.	.	●	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		March 5		§	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		March 22		.	.	.	.	?	.	.	.	±	±	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		May 20		.	.	.	.	.	.	●	±	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		June 22		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		July 21	Several	.	.	.	.	±	.	.	.	±	±	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		July 21		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Aug. 1		.	.	.	.	±	.	●	●	±	±	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Aug. 15		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Aug. 18		.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Sept. 20		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Sept. 27		.	.	.	.	+	.	.	.	●	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 6			.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 14	2	.	.	.	.	+	.	.	.	●	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		Oct. 14		.	.	.	.	+	.	.	.	●	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 21		.	.	.	.	+	.	.	.	●	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Dec. 11		§	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 18		.	.	.	.	+	.	.	.	±	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V	1865	Jan. 9		.	.	.	+	.	±	±	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
B		V	1865	Feb. 4		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Feb. 8	2	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Very heavy"		March 5		.	.	.	±	±	●	.	●	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		March 7	2	.	.	.	±	±	●	●	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		March 8	6	.	.	.	+	±	●	●	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		March 30		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		April 15		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	●	±	±
B		V		April 18		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		April 26	Shocks	§	.	.	.	●	.	.	●	●	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		May 24		.	.	.	.	+	.	.	.	●	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII?		May 24		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Sept. 22		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X?	IX		Oct. 1		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI+		Oct. 1		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 3		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X?	IX		Oct. 8	Very mny.	§	●	.	.	±	.	.	.	+	.	.	.	+	●	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VIII		Oct. 8		§	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Oct. 12	Many	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Oct. 13		.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Oct. 14	Many	§	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Oct. 15		.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Nov. 24	Shocks	.	.	.	.	+	.	.	.	+	.	.	.	●	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII		Dec. 15	9	.	±	+	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V	1866	Jan. 25	Shocks	.	.	.	+	●	±	.	●	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Feb. 15	Shocks	.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	X	IX		Feb. 17		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		March 26		.	.	.	.	±	.	.	●	+	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		May 30		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		IV+		June 5	7	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		July 14		.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		"During summer"		.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		X	1867	Jan. 8		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Nov. 30		.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII		Dec. 1		.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V	1868	March 24		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		May 7		.	.	.	+	●	+	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A	X?	IX?	1868	May . .		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
A		VII		June 2		.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII		July 24		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.
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B		VI		Aug. 31		.	.	.	.	+	.	.	.	±	.	±	±	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX		Sept. 3-6	500±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	+	.	.	.	.	.	.	.	.	.
A		. . .		Sept. 6-11	200±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	+	.	.	.	.	.	.	.	.	.
A	IX-X	. . .		Sept. 13-15		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	+	.	.	.	.	.	.	.	.	.
A		. . .		Sept. 17-19	75±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	+	.	.	.	.	.	.	.	.	.
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A		"More severe"		Sept. 20-22	100±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	+	.	.	.	.	.	.	.	.	.
B		VIII		Sept. 26		.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A B	X			October		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.
A		"Very severe"		October 3	50+	.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX		October 21	50+	§	.	.	?	?	.	.	?	•	?	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Smart"		October 23	4+	.	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Strong"		October 25	2+	.	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		October 26		.	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		October 27		.	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Nov. 4	2	§	.	.	.	±	.	.	.	±	.	.	?	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Nov. 5		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Nov. 17		.	.	.	.	±	.	.	.	±	.	±	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V	1869	Jan. 7	2	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		Jan. 28		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Jan. 29		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		April 1		.	.	.	±	±	.	?	?	+	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		V		June 12		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		. . .		June 25		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Sharp"		July 23		.	.	.	.	+	.	.	.	?	.	.	.	?	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV?		Sept. 13		.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V?		Sept. 13		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	?	?	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		Sept. 14		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	±	.	.	.	.	.	.	.	.	.	.	.	.
B		V+		Oct. 7		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	.	.	.	.	.	±
A		VIII		Oct. 8		.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 15		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	±	.	.	.	.	.	.	.	.	.	.	.	.
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Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		V	1869	Dec. 20		.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII?		Dec. 26	26+	§	.	.	.	.	.	.	+	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IX		Dec. 27		.	.	.	.	.	.	.	+	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V	1870	Jan. 3		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	.	.	.	.	.	±
A		V		Feb. 17	2	.	.	.	+	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		April 2		.	.	.	.	±	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Aug. 6		.	±	±	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Aug. 9		.	+	±	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...	1871	Feb. 6	2	.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX?	VIII		March 2	2+	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		April 2	2	.	.	.	.	±	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V+		June 6	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI?		July 5		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	?	.	.	.	.	.	.	.	.	.
A		VI		July 11	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
A		V?		July 12		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 12		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VIII	1872	March 17		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
B		V?		March 25		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		X		March 26	1000+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
B		V		March 29		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	+	.	±	?	?	.	.	±	+
A		V		April 3	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
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B		VI		April 11	5±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.
B		VI		April 13		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
B		VII		April 18		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
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A		...		May 1		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII		May 17		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
A		VII		Sept. 14	Shocks	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	•	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 12		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		Oct. 24		.	.	.	±	±	.	.	?	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V	1873	Feb. 3		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Aug. 29		.	.	.	.	±	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 12		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X?	VIII		Nov. 22		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	?	±	±
B		V		Dec. 3		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V	1874	March 5		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
B		V	1874	June 11	2	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI	1875	Jan. 24	2	§	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		June 18		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Aug. 8		.	.	.	.	+	.	.	.	±	.	.	.	❢	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Oct. 14		.	±	❢	❢	+	.	.	.	±	.	.	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Nov. 2		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	±
A		V		Nov. 7		.	.	.	.	±	.	.	.	❢	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A	V±	III?	1876	Jan. 21		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		VI	1877	Jan. 13		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
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B		V		May 30		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	❢	❢	❢	.	.	.	.	.	.	.	.	.	.	.	.
A		...		June 23	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	❢	.	.	.	+	±	.	.	.	.	.	.	.
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A		VI	1878	May 8		.	.	±	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		V?	1879	Aug. 10		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	❢	.	±	±	±	❢	.	❢	.
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B		V		April 12		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
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Sub-Groups	INTENSITY		Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		V	1881	April 10	Several	§	.	.	.	±	.	.	.	±	.	.	.	?	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		June 30		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	+	±
A		V		July 3		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
B		V		Sept. 18		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		V		Nov. 13		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		V	1882	Jan. 26	2	.	.	.	.	±	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		March 6	2+	§	.	.	.	+	.	.	.	±	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		April 13		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		June 27	2		.	.	±	±	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		July 15			.	.	.	±	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
B		VI+		Aug. 13	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.
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B		V		Oct. 8		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	+	±
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B		V		Oct. 20		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Oct. 31		.	.	.	+	±	?	?	?	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Nov. 11		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		Dec. 19	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	±	.	.	±	.	.	.	.	.	.	.	.
B		V	1883	March 21		.	.	.	.	±	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		March 21		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		March 30	9	.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Sept. 5	2±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	±	+	.	.	.	.	?	.
A		V		Oct. 8? 9?	3	.	.	.	.	+	.	.	.	.	.	?	+	.	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	VI?	V		Oct. 10		.	.	.	.	±	.	.	±	+	.	.	.	?	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VIII+		Oct. 22	2	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		VII	1884	Jan. 27	2	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		VI		June 6		.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V	1885	Jan. 26		.	.	.	±	±	?	±	?	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X?	VIII		Jan. 30	100+	§	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Sub-Groups	INTENSITY Wood	INTENSITY Holden	YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
B		V?	1885	Feb. 6		.	.	.	±	¡	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Feb. 7	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		March 30		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		VI		April 11		.	.	.	.	+	.	.	.	±	.	.	.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		III		April 11		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
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B		V		July 9	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	¡	.	.	.	±	±	±	.	±	.	.	.	.
A		VI		July 23		.	.	.	.	±	.	.	.	+	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII		July 31		.	.	.	+	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		IV	1886	May 26	4	.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		IV		Oct. 15		.	.	.	.	¡	.	.	¡	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		Dec. 6		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Sharp"	1887	Jan. 31		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	±	.	.	.	.	.	.	.	.
B		"Heavy"		May 12		.	.	.	+	±	¡	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		May 23		.	¡	±	±	¡	.	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VIII		June 3		§	.	.	.	.	.	.	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		June 24		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		July 6		.	.	.	.	±	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Aug. 13		§	.	.	.	±	.	.	.	.	.	±	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 12		.	.	.	.	±	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Dec. 3	2	.	±	±	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Dec. 4		§	.	.	.	¡	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 5		.	.	.	±	±	±	.	.	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 6		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII		Dec. 16	3	.	+	¡	¡	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Dec. 25		.	.	.	+	¡	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		. . .	1888	Jan. 26?		.	.	.	+	¡	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	V+	V		Jan. 29		.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII?		Feb. 18	3	.	+	±	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII?		Feb. 29		.	±	+	+	+	¡	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V or VI		Feb. . .		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		VI	1888	March 7		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	❢	❢	±	❢	❢	❢	.	±	±
B		V		March 28		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		April 12		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	.	.	.	.	.	+
A	IX-X	VIII		April 28	2-3	.	.	.	.	.	.	❢	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		April 30	2	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V to VII		Sept. 17		.	.	.	.	+	.	.	.	±	❢	.	.	❢	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI?		Oct. 3	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	❢	❢	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Oct. 5		.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Oct. 24		.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Nov. 4		.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII?		Nov. 18	3	.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V?		Dec. 11		.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI	1889	Feb. 6	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	.	.	.	.	.	+
A	IV	III		April 14		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		April 24		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		May 1		.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
		"Sharp"		May 1		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	❢	.	.	.	±	+	.	.	.	.	.	.	.
A		VIII		May 19		§	.	.	.	.	.	±	+	+	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	V±			May 26		.	.	.	.	+	.	.	.	±	.	.	.	❢	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	V	...		June 2		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X?	VIII		June 19	28+	.	.	.	.	.	.	.	.	.	.	.	.	.	±	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	VI	...		July 10	6+	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
B		V		July 25		.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII		July 31		.	.	.	.	±	.	❢	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII		Aug. 27	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	❢	.	❢	❢	±	.	±	+	±
A		...		Sept. 24		.	.	.	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI+		Sept. 29		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Very severe"		Nov. 15		.	.	.	+	±	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	VI	V	1890	Jan. 15	2	.	.	.	.	±	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Quite heavy"		Jan. 18?		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		.	.	.	❢	.	.	.	❢	±	±	.	❢	.	.	.	.
A		...		Feb. 5	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	❢	.	❢	+	±
A		VI		Feb. 9	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	❢	.	.	❢	+	±
A		VI+		Feb. 15		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	❢	.	.	.	.	❢	+
A	IX-X?	VIII		April 24	13+	.	.	.	.	+	.	❢	.	±	.	.	.	.	.	.	.	+	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		June 29	3		.	.		.	±	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		June 30	3±	.	.	.	.	+	.	.	.	±	.	.	.	❢	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		July 1		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
B		"Sharp"	1890	July 4		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		July 24		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	±	.	.	±	.	.	.	.	.	.	.	.
A		...		July 26	Several	.	¡	±	±	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX?		Aug. 23		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*	.	.	.	.	.	.	.	.	.	.
A		...		Sept. 3		.	.	.	.	±	.	.	.	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Severe"		Sept. 19	2	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	¡	.	.	.	.	.	.	.	.	.	.
B		"Sharp"		Oct. 3		.	.	.	±	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		Dec. 4	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*	.	.	.	.	.	.	.	.	.	.
A		VII	1891	Jan. 2	2	.	.	.	.	*	.	.	.	±	¡	±	.	¡	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B	V	...		Feb. 24		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*	.	.	.	.	.	.	.	.	.	.
B		"Sharp"		April 13		.	.	.	±	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		May 8		.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Very heavy"		May 19	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		June 22	Shocks	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	¡	.	+	¡	¡	¡	.	.	.
A		V		June 28	Double	.	.	.	.	±	.	.	.	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		July 13		.	.	.	.	±	.	.	.	±	.	±	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		July 17		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		Aug. 9		.	.	.	.	±	.	.	.	±	.	±	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		Aug. 11	3	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Very severe"		Sept. 23		.	.	.	±	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII		Oct. 11	3	.	.	+	+	¡	±	+	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A?		VI?		Oct. 13		.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI?		Oct. 14	4	.	.	+	+	¡	±	+	±	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI	1892	Feb. 5		.	.	.	.	±	.	.	.	+	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X?	VIII		Feb. 23	Many	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	¡	.	.	.	+	.	.	±	+
A		VII		Feb. 24		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	±	+
B		"Severe"		March 13		.	.	.	+	¡	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	X	IX		April 19	Many	.	.	.	.	.	.	±	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		April 20	7+	.	.	.	.	.	.	±	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII		April 21	5+	.	.	.	.	.	.	±	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Very severe"		April 29	2	.	.	.	.	.	.	±	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		May 28	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	.	±	.	.	±	+
A		"Heavy"		June 14		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	¡	.	¡	.	±	.	.	±	+
A		"Heavy"		July 26		.	.	.	±	.	¡	.	¡	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V		Aug. 18		.	.	.	.	±	.	.	.	+	¡	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		Sept. 25		.	.	.	.	¡	.	.	.	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		Oct. 30		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		VII	1892	Nov. 13		.	.	.	.	+	.	.	.	!	.	.	±	!	.	.	.	+	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		Nov. 24		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		V	1893	Jan. 13		.	.	.	.	±	.	.	.	+	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Severe"		Feb. 21		.	.	.	.	.	.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		March 3	2	§	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		March 18	13	§	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Very sharp"		March 30		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	●	.	.	.	.	.	.	.	.	.	.
B		"Sharp"		March 31		.	.	.	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X	VIII		April 4	4+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	.	!	.	.	.	.	.	.
A		VIII		April 8-9	Many	§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	±	.	.	.	.	.	.
A		"Severe"		April 13	4	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII		May 18	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	±	!	+	!	!	!	.
B		VI		May 18	2	.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		May 18		.	.	.	.	.	.	.	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII?		June 1	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	±	.	+	.	.	.	.
A		VI?		June 30	2	.	.	.	+	.	.	.	!	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		July 12		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		July 22		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VIII?		Aug. 9		.	.	.	+	±	±	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Aug. 27		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Sept. 1		.	.	.	.	+	.	.	.	±	.	.	±	!	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Quite severe"		Sept. 6		.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		Oct. 15		.	.	.	.	±	.	.	.	±	.	±	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Dec. 12		.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Sharp"		Dec. 17		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	+	.	.	.	.	±	±
B		"Heavy"	1894	Jan. 24		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+
A		"Sharp"		Feb. 8		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	!	.	!	!	!	!	.	!	!
B		...		July 13		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		July 14		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	!	!	.	.	.	.	.	.	.	.	.
A		VII?		July 29		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	+	.	±	.	.	.	.	.	.
A		"Heavy"		Sept. 30	2	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		Oct. 17		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	!	.	+	.	.	.	.	±	±
A		VIII		Oct. 23	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	!	+	±
A		VII		Nov. 14	Many	§	.	.	.	.	.	.	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Heavy"		Nov. 15	3+	§	.	.	.	.	.	.	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Heavy"		Nov. 17		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	!	±	±
A		VII		Nov. 18	6+	§	.	.	.	.	.	.	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	Holden																																			
A		...	1894	Dec. 23	Shocks	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	±
B		"Heavy"	1895	Jan. 23		.	.	+	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VII		Feb. 28		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*	.	.	.	.	.	.	.	.	.	.
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B		"Sharp"		April 1		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Sharp"		April 17		.	.	.	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Severe"		May 1		.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V+		Nov. 7	Double	.	.	.	.	±	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Heavy"		Dec. 8		.	.	.	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VII	1896	Jan. 27	3	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Sharp"		Feb. 13		§	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		"Severe"		July 3		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	+	±
B		"Sharp"		July 23		.	.	.	+	.	.	.	±	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		VI		Aug. 17		.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		Oct. 19		.	.	.	+	?	±	?	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		VI		Nov. 11		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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		(McAdie)																																			
B	IV±	...	1897	March 6	5	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Heavy"		March 15		.	±	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		May 15		.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	VIII-IX	...		June 20		.	.	.	.	+	.	.	.	±	?	.	.	?	?	.	.	+	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.
B	VI±	...		July 19	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	±	.	+	.	.	.	.
A		...		July 26		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		Sept. 17		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		"Heavy"		Oct. 17		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		...	1898	Feb. 15	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	*	.	.	.	.	.	.	.	.	.	.
A	VIII-IX	VII+		March 30		.	.	.	+	±	.	.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	IX-X	...		April 14	22	.	±	+	+	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		April 18?	9	.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Severe"		April 25		.	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		May 2	2	.	.	.	.	+	.	.	.	±	.	.	.	?	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		...		May ..	Frequent	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	VI+	"Heavy"		June 3		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	±	+	±	.	.	.	.	.	.
A		"Severe"		June 8	3	.	+	±	±	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	McAdie																																			
A		...	1898	June 9		.	±	±	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
B		"Sharp"		June 30		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	?	?	±	.	±	.
B	V?	"Severe"		Sept. 9		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		III-IV		Dec. 7		.	.	.	.	?	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Sharp"	1899	Jan. 13		.	.	.	±	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		"Sharp"		Feb. 10		.	.	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	VII+	"Severe"		April 16		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		...		April 18		.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	V?	III-IV		April 30		.	.	.	.	+	.	.	.	±	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		IV		June 1		.	.	.	.	+	.	?	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	V+	...		June 11		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	±	.	.	.	.	.	.	.	.	.
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A	V+	III		July 6		.	.	.	.	+	.	.	.	±	?	.	.	?	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.
A	V+	III		July 22		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	+	±
A	V+	III		Aug. 4		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A	IX	IV		Dec. 25	Many	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	.	?	.	?	±	●
A		...	1900	Jan. 14		.	.	.	.	±	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		"Heavy"		May 20		.	.	.	.	.	.	.	.	+	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		...		Nov. 19		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	±	.
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A		...	1901	Jan. 21		.	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A	VI+	...		March 2		.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	±	?	?	?	.	.	.	.	.	.	.	.	.	.	.
A		...		March 6		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	?	?	.	.	.	.	.	.	.	.	.	.	.	.
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Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	McAdie																																			
A		...	1901	Aug. 7		.	.	.	.	+	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A	VIII-IX	"Severe"		July 30		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	±	+	±	.	.	.	.	.	.
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Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
	Wood	McAdie																																			
A		...	1904	Jan. 10		.	.	.	±	+	.	!	!	!	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Sub-Groups	INTENSITY		YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22′	23	24	25
	Wood	McAdie																																			
B		V	1906	April 18		.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A		V		April 18		.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		"Very heavy"		April 26		.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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A		"Sharp"		Aug. 19		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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B		VI	1907	Jan. 8		.	.	.	.	●	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

There follows a detailed discussion of certain shocks of Group I in relation to possible generating faults.

All shocks recorded in the catalogs for the California region prior to 1850 are subject to mention here. Subsequent to 1850 only selected shocks are discussed. This procedure is followed since it is considered that in the early days only comparatively strong earthquakes were ordinarily recorded.

A DETAILED DISCUSSION OF THE CORRELATION OF CERTAIN EARTHQUAKES WITH FAULTS WHICH MAY HAVE GENERATED THEM.

(1) B .... 1769, April 11. San Diego.

The record affords no basis for judging the intensity and the source can be estimated only in the vaguest way. The shocks of the following July may throw some light on this. See (2).

(2) A VI? X? 1769, July 28. The Los Angeles region.

Four violent shocks. Many more during the following week. (These after-shocks indicate a higher intensity than is ascribed to this occurrence in the catalog.)

(From the diary of Miguel Costanso,[18] on march from San Diego towards Monterey): "Friday, July 28.— . . . At this place we experienced a terrible earthquake, which was repeated four times during the day. The first vibration or shock occurred at one o'clock in the afternoon, and was most violent; the last took place at about half-past four. . . . To this place we gave the name of Rio de Los Temblores. . . . *From San Diego, 33 leagues.*"

These shocks alarmed the native Indians; and on five succeeding days the members of this expedition, on the march and living in camp in the open, noticed strong after-shocks. There seems little doubt that this was a shock of the first class, with an intensity of X in its epifocal region.

When these shocks occurred these travelers were in the vicinity of San Pedro Bay, on some old maps called Bahia de Los Temblores. A movement on almost any of the faults of the southern part of the Coast Mountain province *might* have produced such a disturbance; but one or more of the following, taken in order of probable importance, seems the more likely source:

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[18] The Portola Expedition of 1769-70, Diary of Miguel Costanso. Teggart, F. J., Ed.; Publ. Acad. Pacific Coast History, August 1911.

the San Pedro Submarine fault-zone; the Tejon–Colorado segment of the San Andreas fault; the San Jacinto fault; the San Gabriel fault; or the Elsinore fault. The Whittier fault, the Santa Ana fault and the Santa Monica fault are very unlikely possibilities.

(3) B .... 1770, ... San Gabriel.

Called *El Valle de Los Temblores* by Fr. Junipero Serra in a manuscript of 1778.

The occurrence of shocks at San Gabriel with such frequency as to win this name for the valley suggests activity of the San Gabriel fault. However, the shocks may very well have had a somewhat more distant origin. Considerable force is lent this latter opinion since a majority of the shocks of later years cannot be ascribed to this fault with much probability.

(4) A X 1790? ...... The region of Owens Valley.

An Indian tradition of a shock similar to that of 1872, affecting the same region.

It is practically sure that any such disturbance would have been caused by slipping within the Mono–Tejon segment of the Major Sierra fault-system.

(5) B .... 1800, October 11-*18*-31. San Juan Bautista.

A series of shocks, sometimes as frequent as six in one day. The most severe shock occurred on the 18th.

With great probability this group of earthquakes may be considered as caused by movements on the southern portion of the Point Arena–San Juan segment, and the northern portion of the San Juan–Tejon segment of the San Andreas fault.

(6) B .... 1803, April ... San Gabriel.

No details of behavior are given.

Besides the San Gabriel fault, attention must be directed to the Tejon–Colorado segment of the San Andreas fault, the San Jacinto fault, the Elsinore fault, and the Santa Monica fault,—in the order of probability.

(7) B VIII 1803, May 25. San Diego.

Damaged the Mission Church slightly.

Owing to such violence at San Diego, the San Pedro Submarine fault-zone, the San Jacinto fault, the Elsinore fault or the Santa Ana fault, in order, would seem the more probable places for the genesis of this shock; but it is not impossible that one of the more distant faults was active.

(8) B VIII 1806, March 24. Santa Barbara.

Church walls cracked.

Most reasonably considered as caused by movements on the San Pedro Submarine fault-zone, the San Gabriel fault, the Santa Ynez fault or the Tejon–Colorado segment of the San Andreas fault; but possibly to be ascribed to the San Luis Obispo fault.

(9) B VIII 1808, June 21 to July 17. San Francisco.

Eighteen shocks altogether. Adobe walls seriously damaged.

It is reasonably sure that this disturbance had its origin on the Point Arena–San Juan segment of the San Andreas fault, or upon the Haywards fault. As is the case in many instances of shocks specified, it is here quite impossible to discriminate confidently between these faults as generatrices.

(N. B.: This note will be referred to frequently in connection with similar shocks.)

(10) A VIII+ 1812, May ... Southern California.

Nearly continuous shocks for more than four months.

It is possible that these shocks should be regarded as fore-shocks of the catastrophe which is discussed in the next item. Judged apart from this, it is quite impossible to form any definite opinion regarding their places of origin. The degrees of probability are indicated as well as possible in the tables.

(11) A IX 1812, September, October or December? Sunday?
X Coast region of Southern California.

Serious damage to buildings and loss of life at San Juan Capistrano, and at Santa Ynez; destructive at San Fernando and at San Gabriel; a seismic sea-wave at Refugio and damage to a ship thirty-eight miles from Santa Barbara. A multitude of after-shocks, with continuous vibration of the ground at Santa Barbara for eight days.

As is indicated in Holden's catalog, there is confusion as to the date, or dates, of this great shock, or shocks. At San Juan Capistrano, October 7th is given as the date of the great shock in what is perhaps the best account, but other dates are given. There is mention of shocks on October 8th, October 21st and December 8th. At San Fernando, Santa Ynez, Santa Barbara and Refugio the date December 21st is given. Obviously it is possible, even probable, that more than one strong shock occurred; but, with so confused a record, this cannot be assumed.

If the widespread destructive intensity recorded was the result of a single earthquake, then assuredly that was a seismic disturbance of the first magnitude, reaching high values in grade X of the R.-F. scale. (Even if two distinct strong shocks occurred, X of the scale is indicated.) In the case of a single shock, the records strongly suggest a submarine origin.

As a speculation merely, it is interesting to note that the phenomena could best be accounted for as the result of two, or more, strong shocks,—one generated either on the north end of the San Pedro Submarine fault-zone, the Santa Ynez fault or the San Gabriel fault, wreaking havoc at Santa Ynez, Refugio, San Fernando and San Gabriel; the other caused by movement on the south end of the San Pedro Submarine fault-zone, the San Jacinto fault, the Elsinore fault or the Santa Ana fault, causing destruction at San Juan Capistrano.

However, the sea-wave at Refugio and the strong shock experienced by the ship thirty-eight miles from Santa Barbara point emphatically to an earthquake of great energy having a submarine origin; and, in view of the state of the record, the writer is forced to regard this as the most probable explanation of the whole confused occurrence. It is not unlikely that the confusion as to date arises from the recording of strong after-shocks, of which there must have been many in a sequence noted for many months at Santa Barbara.

(12) B .... 1812, ... San Francisco.
(X)? Severe shocks with tidal waves.

Unless tidal waves from the great shock in the south entered San Francisco Bay and thus washed over the site of the Plaza—an unlikely contingency—the Point Arena-San Juan segment of the San Andreas fault, or the Haywards fault, are the more probable places of origin for this earthquake. Mention of tidal waves makes the San Andreas fault the more probable source in the present instance.

A IX 1813 or 1815. Santa Clara Valley?
(X)? According to a statement of John Gilroy, this earthquake shook down all the buildings "in the region"—meaning probably the Santa Clara Valley? See (9).

(13) B .... 1815, January 18. Santa Barbara.
Five shocks.

B .... 1815, January 30. Santa Barbara.
More shocks.

B .... 1815, July 8-9. Santa Barbara.

The foregoing shocks, though possibly from one point of view to be regarded as a single period of seismic activity, must here be considered as separate events generated in all probability by the same fault,—a zone of disturbance which cannot be fixed upon with any certainty. Perhaps most probable is the San Pedro Submarine zone, but the San Gabriel and the Santa Ynez faults are also likely places of causation. The San Juan-Tejon segment of the San Andreas fault is not an impossible origin, nor is the San Luis Obispo fault.

B VIII 1818, ... Santa Clara.
Church damaged. Some doubt as to reality of shock. See (9).

A .... 1821, January 1. San Buenaventura-San Luis Rey.
Severe shock. See (7).

B .... 1829, September ... San Francisco.
Several very severe shocks. See (9).

(14) B VIII 1830, ... San Luis Obispo.
Church injured.

Movement on the San Juan-Tejon segment of the San Andreas fault was the probable cause of this shock, but it is not impossible that it emanated from the San Luis Obispo fault or the Templeton fault, both of which pass in the near vicinity of San Luis Obispo. If these latter were known to be active frequently the problem would be quite ambiguous.

(15) B .... 1836, April 25. Monterey.
No details.

The Point Arena-San Juan segment is, all things considered, the most likely place of origin in this instance; and next in importance is the Monterey Submarine fault-zone. It is not impossible that the source was on the Pajaro, the Santa Lucia, the San Gregorio or the Haywards fault. The first named is considered the most probable, on account of its known frequent activity and its proximity to the town.

(16) A VIII 1836, June 9-10. Central California.

(X)? Region affected was approximately the same as that shaken in 1868. See account of that shock. " . . . great fissures in the earth, and the shocks continued for a month."

May it be that the word fissure in this record refers to phenomena now known to characterize the surface outcrop of a fresh fault-slip,—the system of fractures we designate as a fault *trace?* The number of aftershocks also indicates an intensity higher than VIII.

In this case it is very slightly more probable that the place of genesis was on the Haywards fault. See (9) and (17).

A VIII 1838, June–July. San Francisco–San Jose–Monterey.

See (9) and (17).

(17) A IX 1839, ... Central California.

(X) "Adobe walls seven feet thick were cracked from top to bottom . . . and one immense fissure extended from Lone Mountain (?) to Mission San Jose."

This precise observation very strongly suggests fault *trace* phenomena, and thus points to an intensity of X in close proximity to the epifocal region.

With very great probability the Haywards fault may be taken as the generatrix of this shock, but it is possible that a short, unnamed fault just to the east of it, running southeastwardly from near Mission San Jose to near Mt. Hamilton, was the actual place of origin. If Lone Mountain (?) is either Mt. Hamilton or Mission Peak of the present day, this shorter fault is the most probable source. But, owing to the scarcity of place-names and named landmarks at the remote date in question, the Mission San Jose and Lone Mountain (?) were very likely mentioned to fix in an appropriate way only the course of the fissure, rather than as precise end-points for it. If this is the truth of the matter, the Haywards fault is, after all, the most probable generatrix. It is possible that there was contributory, or sympathetic, activity on the Point Arena–San Juan segment of the San Andreas fault.

B IX 1840, January 16-18. Santa Cruz.

Church tower overthrown. Tidal wave. See (15).

(18) B VII 1841, July 3. Monterey.

Felt also at sea.

B .... 1841, "two successive months of summer." Monterey.

One hundred and twenty earthquakes, mostly weak.

Since one of these shocks (for that of July 3d is most probably one of the series) was noted at sea, it is possible that the Monterey Submarine fault-zone was their place of genesis. Still the great number of the shocks recorded leads to the inference that they emanated from the Point Arena–San Juan segment of the San Andreas fault. The possibility of their originating on the Pajaro fault must not be overlooked. The San Gregorio fault and the Santa Lucia fault are less likely possibilities, only because there is less suggestion of their frequent activity. See (15).

(19) A VIII 1843, June 23. California, extending into Mexico.

While the region which was affected was indicated far too vaguely to allow of a determination of the place of origin, even approximately, it seems desirable to point out that disturbances originating on the San Jacinto fault, the southeastern end of the San Andreas fault, the Elsinore fault or those referred to as the Carizo faults, would shake up such an area. See also (20).

(20) B .... 1849, September 16. Santa Isabel, between San Diego and the mouth of the Rio Gila.

B ... 1849, September 22. Twelve miles from Curisco (Carizo?) Creek, between Santa Isabel and the Gila.

These shocks are recorded only from the center of a district traversed by the San Jacinto, the Agua Caliente and the Elsinore faults, and those which are here referred to as the Carizo faults. It is possible that any of these was the generatrix; but on account of its proved activity, the San Jacinto fault is the more likely source. The remote date and the unsettled character of the district, with few place-names, must not be forgotten.

In the remaining portion of this detailed discussion only selected shocks are considered.

(21) A .... 1850, August 15. San Diego and on the Gila.

(22) A V 1851, June 13. San Francisco, San Luis Obispo, San Fernando.

Smart shock.

This certainly was not a single shock felt so lightly throughout so extended a district, but rather a series of light shocks caused by minor local movements. The records, however, contain no information bearing on this. The disturbances may have been due to uneasiness at several points on the San Andreas fault, but local movements on other faults are also possible. See the table.

(23) A .... 1851, November 26. Coast of California from 37° to 40° N. Lat.

Eleven shocks; no details.

The number of shocks and the extent of the region affected give probability to the opinion that there was movement on the Punta Gordo–Point Arena and the Point Arena–San Juan segments of the San Andreas fault. Possible independent or contributory activity along the Eureka–Ukiah–San Pablo line, and the Monterey Submarine fault-zone, must not be overlooked.

(24) A .... 1852, October 26. Southern California.

(X)? Eleven shocks at San Simeon, Los Angeles and San Gabriel. The disturbance was noted also at San Luis Obispo, San Diego, and the Colorado River. Aftershocks at short intervals during the next six days throughout Southern California.

Holden did not attempt to estimate the intensity. If the shocks were felt simultaneously throughout the area of report, X is the least value which can be assigned for it. If it was a series of fore-shocks for the earthquake of November 27-30 following, no such high intensity need be assumed. There is possible confusion as to the date. See also (28).

If the area designated was affected by a single seismic disturbance it emanated most probably from the San Juan–Tejon and the Tejon–Colorado segments of the San Andreas fault. It is possible that independent or contributory shocks were generated by movements on the San Luis Obispo fault, the Templeton fault, the Santa Ynez, the San Gabriel, the Elsinore or the San Jacinto faults. If the disturbance was a series of local shocks together affecting this wide area, the faults above mentioned are the more likely seats of origin as well. See the table.

(25) A VIII 1852, November 9. Fort Yuma.

or Fissures and rock falls; activity of mud volcanoes.
IX? Was the intensity perhaps as high as X?

(X)? The place of report, though beyond the ***known*** extension of the San Andreas fault, lies on the trend of this great rift to the east-southeast of its known extent. It is probable that the fault continues in this direction, and it is not unlikely that the shock originated on it. The mud volcano, however, was found about forty-five miles southwest of the fort. This thermal activity was probably on the line of the San Jacinto fault, known to be active at times; and therefore this zone in this instance must be regarded as the most probable place of origin.

(26) B VIII 1852, November 22. San Francisco.

Severe shock eight miles *southeast* of San Francisco. Next morning a ***fissure half a mile wide and three hundred yards long*** was discovered, through which the waters of Lake Merced were flowing to the sea. (The italics are introduced here by the present writer to emphasize an apparent error, at any rate a sure want of precision, in the record.)

(27) B .... 1852, November 24. San Francisco.

Perrey says that the waters of Lake Merced disappeared. See (26).

It is impossible to learn whether these two dates refer to the same shock or to different events. A fissure,—or what seems more probable, from the dimensions given, a zone of fissures and cracks leading from Lake Merced to the sea,—suggests possible activity on the San Bruno fault; for such a belt of fissures would lie almost precisely along its course. This, however, is the only instance in all the records in which activity on this fault is suggested with either force or probability. Moreover, slipping on the near-by San Andreas fault would undoubtedly be competent to produce such a belt of fissures in the sand and alluvium which separates Lake Merced from the sea.

(28) A .... 1852, November 26 (October 26?). Southern California.

Eleven strong shocks at San Simeon, Los Angeles and San Gabriel. See (24).

A IX (X)? 1852, November 27-30. Southern California.

"Continued shocks disturbing an area of over three hundred miles square, extending east from San Luis Obispo to the Colorado River, and ***north*** to San Diego." (Of course the word here italicized should be ***south*** or else San Diego is not meant.) "The shocks opened fissures at least thirty miles long in Lockwood Valley."

This last suggests fault-trace phenomena, and, together with the great area disturbed, points with much force to an intensity of grade X throughout a considerable district.

This seismic disturbance seems almost certainly due to a slipping of considerable extent along the San Juan–Tejon and the Tejon–Colorado segments of the San Andreas fault. See also (24).

(29) B IX 1852, November 29. San Diego.

"Shock lasted two minutes. The earth seemed to vibrate to-and-fro some five or six inches."

So great an estimate of the amount of movement could not be accepted without instrumental proof; yet it is clear that a strong shock was experienced on this occasion; its estimated duration, though evidently not wholly reliable, points to an origin at considerable distance.

Referring to the series of strong shocks in Southern California in the autumn of this year, of which this was one, it seems probable that the seismic origins were not confined to the San Andreas fault. This shock, for example, was recorded only at San Diego. Contributory movements on other faults very likely occurred. The San Jacinto fault is possibly a source, also the Elsinore fault. The Carizo fault-zone is not an impossible source; but the San Pedro Submarine fault-zone seems most likely of all. See also (24) and (28).

(30) A IV 1853, January 2. San Francisco–Bodega–Shasta City.

Activity on the Point Arena–San Juan segment of the San Andreas fault seems most probable,—perhaps with independent movements farther north.

It seems almost certain that the shock felt at Shasta must have been distinct, and have emanated from some indeterminate place of genesis.

(31) A V 1853, March 1. San Francisco, San Luis Obispo, Santa Barbara.

Smart shock.

Probably not all these places were affected by the same shock. Hence it is impracticable to discuss the places of origin, since there is no information as to the area affected by each shock. See the table and (22) and (46).

(32) A .... 1853, September 2? 3? Salinas and the San Joaquin plains.

Four shocks felt.

Whether the shocks were local in each district, or the same shocks were manifested in both, cannot be inferred with any confidence; and, consequently, the place, or places, of origin cannot be determined upon.

(33) A V 1854, January 3. Mariposa and Shasta.

Two smart shocks.

Almost certainly these were distinct shocks in each locality. The place of origin cannot be estimated with confidence in either case.

(34) A V 1855, January 14. Along ninety-four miles of the coast of California.

The part of the coast is not specified; but it seems very likely a shock emanating from the Punta Gorda–Point Arena and the Point Arena–San Juan segments of the San Andreas fault.

(35) A .... 1855, January 24.

"A heavy shock, lasting seven seconds, was felt at Downieville, Sierra county, California. This shock was quite severe at Gibsonville, on the north, at Forest City and Minnesota, in Sierra county; and at Orleans Flat and Eureka, Humboldt county; in Nevada county; at Georgetown and Nashville in Eldorado county, on the south; and at Keystone ranch, in Yuba county, on the west."

Except for the places mentioned in Humboldt county, these localities are in the summit region of the northern Sierra, and those places where the shock was strong lie near to the Major Sierra fault-system. Hence it is likely that the disturbance originated in this zone. But it is possible that some other fault, or faults, constituted the source; for our knowledge of this district is as yet very limited.

With reasonable certainty, the shock felt in Humboldt county may be considered a distinct event whose place of origin probably was associated with those of others so frequently recorded in this district.

(36) A .... 1855, April 7. In Trinity county and Siskiyou county.

In the present state of our knowledge of the geology of this part of the district it is not practicable to attempt a decision as to the place of genesis of this shock.

(37) A VIII 1855, July 10. Los Angeles–San Gabriel.
(IX-X)? Four shocks in twelve seconds. Two unusually heavy sea-waves at Point San Juan. Bells thrown down in the San Gabriel Mission church.

Taken together, the phenomena would appear to indicate an intensity of IX, or perhaps X, in the epicentral district.

Seismic sea-waves are considered to indicate submarine disturbance; hence the vague San Pedro Submarine fault-zone is taken as the most probable origin. Possibly the San Gabriel or the Elsinore fault suffered disturbance also. The Santa Monica fault is a very doubtful source, since no very strong suggestion of its activity at any time can be discovered.

(38) A .... 1855, October 27. Clear Lake, Downieville and Goodyear's Bar.

Almost surely two distinct shocks.

That at Clear Lake was light and is difficult to correlate with any fault considered here.

As to the shock felt lightly at Downieville and more severely at Goodyear's Bar, see (35).

(39) A VI 1856, January 10.

"Severe at Los Angeles and throughout the southern part of the state."

The information is too vague to admit of satisfactory correlation, but the Tejon–Colorado segment of the San Andreas fault, the San Jacinto fault, and the Elsinore fault seem the more likely generatrices. As the table indicates, others are possible.

(40) A IX 1856, "In the fall."
(X)?

"Tulare county." The line of shock "was marked by a fracture of the earth's surface, continuing in one uniform direction for a distance of some two hundred miles."—B. Mss.—Barton, *History of Tulare County*, p. 11.

If the above statement is reliable the phenomena of a fault-*trace* unquestionably are indicated: and in that case an intensity of X is certain. However, it is unlikely that any such fault-trace traversed Tulare county. While loose statements ought not to find place in a county history, everything else indicates that the shock of January 9, 1857, is referred to; and, tentatively, this will be assumed here. See (41).

(41) A IX 1857, January 8-9. San Francisco–Fort Tejon–Fort
X Yuma, etc.

This perhaps is the strongest earthquake ever recorded in the Coast Mountain province of California. Holden judged that intensity of IX on the Rossi-Forel scale was manifested at widely separated localities, such as Visalia, Fort Tejon, San Buenaventura, San Fernando, San Diego, and Fort Yuma; VIII at San Benito, and VI at Sacramento. Though based upon vague and somewhat confused statements, doubtless somewhat exaggerated, in the main these judgments appear quite sound. The meizoseismal region was almost uninhabited. Moreover, actual rupture of the soil cover, accompanied by all usual *trace* phenomena, is now known to have been manifested in the region of the Carissa Plains, near Tejon Pass, and probably in the vicinity of San Bernardino, where "a large fissure was made in the western part of" the town. See also (40). Wherefore the intensity must unquestionably have exceeded the minimum values of grade X of the Rossi-Forel scale throughout a considerable district.

On this occasion indubitable fault displacements at the surface, producing characteristic *trace* topography, took place along the San Andreas fault to the northwest of Tejon, and very probably to the southeast also.

The intensity of IX, at the very least, judged by Holden to have been manifested at San Buenaventura and at San Fernando, suggests contributory activity on the San Gabriel fault, since these places are distant from twenty-five to forty miles from the San Andreas fault.

Since an intensity of IX (some houses thrown down) was reported from San Diego, it is likely that movements also took place on the San Pedro Submarine fault-zone, the Elsinore fault, or *possibly* the San Jacinto fault. Assuredly an intensity of IX at San Diego, distant about eighty miles, could hardly have been the result of movements on the San Andreas fault alone: for this would denote a shock of quite unparalleled energy,—at any rate for the California region.

(42) A .... 1857, April 24. San Jose and San Gabriel.

Distinct shocks.

(43) A VIII 1858, November 26. San Francisco, San Jose and the
(IX-X)? Santa Clara Valley.

Nearly every brick building in San Jose injured.

Since this shock was not reported outside the Santa Clara Valley and was more destructive at San Jose than at any other point, according to the information afforded by the records, it probably originated on the Haywards fault.

(44) A VI 1859, January 25. Trinity and Shasta counties.

In the present state of our knowledge of the geology, and of the behavior of shocks, in this part of the region, it is impracticable to indicate seismic generatrices.

(45) A VI 1859, March 25. San Felipe, Santa Clara Valley, Central California.

Fourteen shocks, one very severe.

Though San Felipe is but a few miles east of the San Andreas fault, whence these shocks might well have emanated, still it is to be noted that the Haywards fault, if it reaches so far southward beyond its present known extension, trends so as to pass very close to this place. The topographic and drainage features near San Felipe and to the north of it hint at such a continuation of the Haywards rift. Some of the minute topographic features peculiar to a fault trace are said to exist nearby. All this, together with the fact that these shocks were reported from no other community, indicates the Haywards fault as origin.

It may not be amiss to point out that, because this event strongly suggests the persistence of the Haywards fault considerably south of its known limit, or else the existence of a fault practically continuous with it, its occurrence is regarded as important in that it exhibits the utility of such a hypothesis as governs this present study.

The shocks of August 2, 1903, and of July 1, 1911,[19] also indicate the southward continuance of the Haywards fault.

(46) A VI 1860, April 16. San Francisco, Fort Tejon, Santa Barbara.

Probably independent shocks were felt at these localities, but it is possible that they were all due to minor movements at different points along the San Andreas zone. See (22) and (37).

(47) A VI 1861, January 12. Trinity county.

No decision can be made as to the place of origin of this shock.

(48) A (IX?) 1861, July 3-4. Amador Valley, Contra Costa county.
(X?) Houses injured; men thrown down; fissures.

Amador Valley, which was the meizoseismal area of this shock, is situated just to the east of the Sunol fault-system. Consequently this must be regarded as the most probable place of genesis, more especially since the shock was light elsewhere. Nevertheless this is the only shock cataloged which can be referred to this system with a great degree of certainty.

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[19] See *Bulletin Seismological Society of America*, 2, pp. 31-39, March 1912.

(49) A VI 1864, February 26.} Various places in Central California
A VI 1864, March 5. } and *also in Visalia*.

On the earlier date the shock is merely mentioned at Visalia, but on the later date the intensity there was estimated at VI by Holden.

As regards the Central California district the distribution of intensity suggests with equal force genesis on the San Andreas fault or on the Haywards fault.

Whether the occurrence of a shock at Visalia on both occasions means independent but coincident events, or sympathetic shocks, or whether the area of strong intensity of both extended thus far, cannot be decided. Except for the time-coincidence in both instances, the shocks recorded at Visalia would be regarded as independent without question.

(50) A .... 1864, December 11. San Francisco-San Jose.

In this instance it is probable that the records refer to the same shock, in spite of a reported difference in time of one minute.

(51) A V 1865, April 26. San Francisco, and many places in California.

On account of want of information it is impossible to estimate the location of the origin of this shock.

(52) A VII? 1865, May 24. Southern California.

Vagueness in the report as to the region affected makes it impossible to indicate the location of the origin.

(53) B V 1865, September 22. Yreka.

On account of our ignorance of the geology, and of the behavior of the shocks, it is impossible even to estimate places of origin for shocks recorded in this district.

(54) AB IX 1865, October 8. Central California, Humboldt county,
(X?) Modoc county.

At least three strong earthquakes occurred on this date, reported from localities separated so widely that there is no probability of their being associated in any way as yet understood.

That which occurred in Central California seems, in all probability, to have been generated on the Point Arena–San Juan segment of the San Andreas fault; but that it may have had origin on the Haywards fault wholly or in part is also possible. Contributory activity of the Pajaro fault is also possible. The intensity of this shock was surely as high as IX, as Holden estimated it, and it may have reached X within a small epifocal tract.

The shock which was felt in Humboldt county probably had the same fault-source as numerous other strong shocks which have occurred in that region. These have been ascribed ambiguously to the Punta Gorda–Point Arena segment and to the Eureka–Ukiah–San Pablo line. In this instance the intensity was estimated by Holden to be VIII, or higher, and though distinct in time from that felt in Central California, in reality this may have been an associated disturbance further north along the same zone.

No attempt can be made to locate the place of origin of the shock which was felt in Modoc county.

(55) A .... 1865, October 14. San Francisco–Monterey.

A disturbance in all probability emanating from the neighboring segment of the San Andreas fault, succeeded by many shocks in the following day or two.

(56) B IX 1866, February 17. Northern California.

A sensational account of a shock, reported to have elevated the bed of the Klamath River "fifteen miles above the Jacksonville road." The place of origin cannot be estimated.

(57) B IX 1867, January 8. Fort Klamath.
(X)?

A very strong earthquake; if the account can be accepted it was one of the greatest earthquakes recorded in this whole region. But, since there is only one place of report, its origin cannot be located.

(58) A IX 1868, May ... Dos Palmas.
(X)?

"Opened a long fissure in the earth." (Fault trace?)

Dos Palmas is located in the trend of the San Andreas fault southeastward beyond the furthest point to which this fault has yet been traced with certainty. Hence, tentatively, this shock may be considered due to motion on this fault. Other possible origins are noted in the tables.

(59) AB .... 1868, October ... Near the head of Kern River.
X

"There is quite a phenomenon on the Sierra Nevadas, at the head of Kern River. The earth has been shaking for more than two weeks—almost a constant shake. It shakes the earth down from the mountain, and makes the earth wave like the sea . . . " (S. F. *Bulletin,* October 17, 1868.)

If reliable, this indicates origin on the Kern fault most probably; but possibly on the Major Sierra fault-system.

(60) A IX 1868, October 21. Central California.
(X)

This is one of three or four great shocks which have occurred in the inhabited parts of California.

Fault-*trace* phenomena were produced; and the intensity certainly reached X in the epicentral tract. Movements of shearing developed fissures and offsets along the course of the Haywards fault in the vicinity of Haywards, San Leandro and Niles. The shock unquestionably emanated in large measure from this fault. However, it is possible that there was contributory activity on some of the neighboring faults, of which the San Andreas seems the most likely supplementary source. In this connection it is noteworthy that Mt. Tamalpais was displaced 5.4 feet (chiefly to the north, presumably for the most part by rebound at the time of this earthquake); and that other points, further to the north and west and at greater distances from the Haywards fault, were displaced even more.

(61) A .... 1868, November 4. San Francisco-Monterey.

Severe at Monterey.

Though perhaps an after-shock of the great earthquake of October 21st, origin on the Haywards rift is not indicated by the record. The San Andreas fault and the Pajaro fault seem at least equally possible sources. The Monterey Submarine zone is also indicated.

(62) A VIII? 1869, December 26. Central Sierra foothill region.

Undoubtedly a strong shock felt with considerable force over a large area underlain by firm rocks for the most part.

The apparent epifocal tract of this shock is not related even approximately to any of the faults or lines under consideration in this study. However, it is possible that there was contributory activity on the Mare Island-Nevada-Carson line.

(63) A VIII 1873, November 22. California and Oregon Coast region.
(IX-X)? Very strong shock.

The vague information indicates a submarine origin on a zone not considered in this study.

A VI 1875, January 24. Butte, Plumas and Sierra counties.

See (35) and (38).

(64) B VI 1877, January 13. Forty-five miles southeast of San Diego.

The place of report was in an unsettled country: it is not far from the southeastward prolongation of the Elsinore fault. The Agua Caliente fault and the San Jacinto fault, extended, though farther from San Diego, would pass not far from the place of report. On account of its known activity, the latter is preferred in the present decision.

(65) A .... 1877, July 9. Sacramento–Carson.

In this instance the records probably refer to different shocks, each felt locally.

(66) A V? 1879, August 10. San Fernando–Santa Monica.
(V+)? Tidal wave at Santa Monica.

On account of the sea-wave it seems most probable that this shock was generated on the San Pedro Submarine zone; if not, then it is likely that its focus lay in either the San Gabriel or the Santa Monica fault.

(67) A V 1881, April 10. Central California.

There is no information on which to base an estimate in this case.

(68) A V 1882, March 6. Monterey–Merced.

Though the origin very likely was on the San Andreas or the Haywards fault, it is noteworthy that the places of report of this shock lie on a line roughly coinciding with the known extent of the Pajaro fault, together with its possible eastward extension toward Merced.

(69) B VIII 1883, October 22. Merced Falls.
(IX-X)? The place of origin of this shock cannot well be associated with any of the faults or lines considered here.

(70) A VIII 1885, January 30. Honey Lake Valley.
(X)? A strong shock, with many after-shocks.

Tentatively, shocks affecting this region are taken as generated on the Honey Lake fault-zone; but our ignorance of the details of the geology and of the seismic phenomena in this part of the country forbids conclusions of definite character.

(71) A V 1885, December 30. Central California.

Accepting the available records, the apparent intensity developed by this shock was distributed in a confusing way, making it unusually difficult to estimate its place of origin satisfactorily.

(72) A .... 1886, September 3. Several California towns.

There is no information as to the district affected; so there can be no estimate of the place of origin.

(73) B VIII 1887, June 3. Carson.

Though shocks have been felt at Carson on occasions when the zone designated as the Mare Island–Nevada–Carson line has been disturbed, it does not follow that shocks felt at Carson should be assigned to this line, for Carson is located near to other faults—some known to be active—which are not specifically considered here.

(74) B VIII 1887, August 13. Point Pinos Light station.

"Very severe shock lasting eleven seconds."

This shock, reported from this station only, is perhaps more strongly suggestive of activity on the Monterey Submarine fault-zone than any other shock considered in this paper. Yet it may have been generated on some other of the neighboring faults.

(75) A VI 1887, December 4. Haywards–San Francisco.

In this instance the epicentral district appears to have been at or near Haywards, so there is a strong presumption of origin on the Haywards fault.

(76) A VIII 1889, May 19. Central California.

In this case it is unusually difficult to judge upon what fault-zone the shock most probably was generated. Intensity of VII or VIII was recorded at a number of places which, taken individually, or in selected groups, point to different faults as the more likely places of genesis. The tables express the dubious, but more probable opinions.

(77) A .... 1889, July 10. Los Olivos.

Shocks in this district, when local, in this study must be considered as caused by movements on the Santa Ynez fault.

(78) A VI 1889, September 29. Wawona, Yosemite.

The place of origin of this shock is probably not to be associated with any of the fault-zones considered in this study.

(79) A VI 1890, February 15. Los Angeles and vicinity.

In the account of this shock there is definite mention of the San Jacinto Peak as the place of origin; but, apart from this definite opinion, there is nothing in the record which points with especial force to genesis upon the San Jacinto fault.

(80) A IX? 1890, August 23. Mono Lake.

Though most probably generated by movements within the Major Sierra fault-system, yet it is possible that movement on a neighboring cross-fault, here designated as the Bodie fault, was the cause of the shock. In this instance, too, a possible volcanic origin for the shock should not be overlooked.

(81) A .... 1890, September 19. Calico, Daggett, Barstow, etc.

The place of origin of this shock probably is not to be associated with any of the faults considered here.

(82) A VII (IX?) 1892, February 23 and 24. Carizo, San Diego, etc.

Beal[20] expresses the opinion that this shock originated on the Agua Caliente fault. However, reports from Ensenada and San Quentin, in Lower California, indicate that the San Pedro Submarine zone must be equally probable.

(83) A .... 1893, March 3. Grass Valley-Carson.

Though the shocks recorded occurred at practically the same time (several minutes difference, but not in excess of probable clock error), yet it seems more likely in this case that distinct shocks occurred at nearly the same time, than that the same shock was felt at both places, for no shaking was recorded at intermediate points.

(84) B .... 1893, March 18. Shelter Cove.

Thirteen shocks.

This disturbance, apparently of considerable energy, most probably had origin on what is designated as the Punta Gorda-Point Arena segment of the San Andreas fault.

(85) A VIII (X?) 1893, April 8-9. District around Newhall.

This shock may have emanated from the Tejon-Colorado segment of the San Andreas fault; but this seems unlikely, for its epifocal region appears to have been southwest of Newhall, rather than north. Either the San Gabriel fault, or some minor neighboring fault, is the more probable place of origin.

There is a remote possibility that this was a *collapse* earthquake, occasioned by the removal of oil from subjacent strata.

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[20] *Bulletin Seismological Society of America*, 5, 138.

(86) A .... 1894, February 8. Los Angeles and vicinity.

The data are too vague to assist in estimating the place of genesis.

(87) B .... 1894, July 13-14. Sierra, east of Fresno.

Correlation is doubtful on account of deficient information.

(88) A .... 1894, November 14 } Carson and the surrounding district.
A .... 1894, November 18. }

The place of origin cannot be estimated from the vague information in the catalog. It is not to be associated, probably, with any of the fault-zones discussed here.

(89) A .... 1896, February 13. Redding-Weaverville-Eureka.

This shock probably did not originate upon any of the faults considered here.

(90) B .... 1896, December 17. Santa Barbara.

Tidal wave only.

There is no information to assist in locating the origin.

B .... 1900, February 28. Winnemucca.

This shock did not originate on any of the faults considered.

(91) B .... 1903, November 18. Imperial.

Severe shock.

This shock may have emanated from the southeast extension of the San Andreas fault, but the place of report lies nearer to the extension of the San Jacinto fault, so that in this instance this latter fault is chosen. Of course the Agua Caliente fault and the Carizo faults must not be overlooked.

(92) A .... 1905, May 15. Nevada City-Oakdale-Yosemite.

This perhaps was not a single disturbance. It cannot be correlated with any confidence with any fault or line under consideration.

(93) A X 1906, April 18. Northern and Central Coast province of California.

It is well known that this shock, "the San Francisco Earthquake," emanated from slipping along the Punta Gorda-Point Arena and the Point Arena-San Juan segments of the San Andreas fault. Nevertheless, in the opinion of the writer, the strong suggestions of contributory activity upon the Eureka-Ukiah-San Pablo line, the Haywards fault, and some unrecognized fault along the western margin of the San Joaquin Valley, should not be lost sight of,—even though, as is clearly recognized, the factor of alluviation makes it impossible to *demonstrate* such action.

(94) A IX 1906, April 18. San Diego–Brawley–Yuma.
(IX-X)

[21] This strong shock, in the afternoon, attracted comparatively little attention, because of the disastrous character of the shock in early morning in Northern and Central California.

Brawley, where the intensity was estimated at IX, is located in the Imperial Valley about ten miles northeast of the southeastward projection of the San Jacinto fault, almost directly on the southeastward projection of an unnamed fault shown by Beal[22] northeast of the Santa Rosa Mountains, and about twenty miles southwest of the projected course of the San Andreas fault southeastward toward Yuma. Brawley appears to have been the place of greatest recorded intensity.

It is impossible to decide which of these faults was the more probable place of origin. Since both the San Andreas and the San Jacinto faults have histories of action, between them there is ambiguity,—while the unnamed fault heads directly for the place of highest known intensity.

(95) A .... 1906, April 19. Localities in Western Nevada.
(X)

It is doubtful if this series of shocks emanated from the Major Sierra fault-system: these cannot be correlated with any other fault or line under consideration.

It seems worth while to point out that the greater part of the whole California region was subjected to greater or less local disturbances in the day or two, and the month or two, following the great shock in the early morning of April 18, 1906.

TABLE II.

In Table II all shocks estimated by the catalogers at intensity less than V of the Rossi-Forel scale are correlated with the faults and lines discussed above.

The table is constructed exactly as Table I except that there is no need for columns for the letters A and B, and for revised estimates of intensity. These therefore are omitted.

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[21] Report San Francisco Earthquake Investigation Commission, 1, pt. II, 413-414.

[22] *Bulletin Seismological Society of America*, 5, 132.

TABLE II.

HOLDEN	YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
..	1850	Jan. 16	3	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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III		Mar. 21	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III		June 28	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III	1851	May 17	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..		Nov. 15	2	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..		Dec. 30	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..	1852	Dec. 26	....	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	?	.	?	.	±	±
..	1853	Jan. 1	....	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	±	?	.	?	.	?	?
..		Jan. 5	....	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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III		Apr. 24	....	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III		Apr. 25; 26?	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III		July 12	....	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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III		Oct. 25	....	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III		Nov. 16	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III		Nov. 18	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..		Nov. 20	50+ shocks since Jan. 1	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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III		Dec. 23	....	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..	1854	Jan. 9	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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III		Mar. 2	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..		Mar. 16±	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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III		Apr. 29	....	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	?	.	.	.	?	±	±	.	±	.	.	.	.
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Holden	Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
..	1854	May 23	....	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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..		Nov. 11	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
III	1855	Jan. 2	Double	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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..	1856	Dec. ?	....	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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HOLDEN	YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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Holden	Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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Holden	Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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Holden	Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	12b	17	1d	18	19	20	21	22	23	24	25
..	1888	Jan. 13	....	.	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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HOLDEN	YEAR	DATE	NUMBER		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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McAdie	Year	Date	Number	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
..	1900	Dec. 5	....				±				+	?																						
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McAdie	Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
III	1901	Nov. 13	....	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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McAdie	Year	Date	Number		1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	13	14	15	16	11b	12b	17	16	18	19	20	21	22	23	24	25
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Report	§																																		

The shocks here treated subsequent to April 11, 1906, are cataloged partly by McAdie and partly in the Report on the California Earthquake of 1906. The estimates of intensity are by various persons, subject to the editorship of McAdie and Lawson.

Following April 18, 1906, the great majority of shocks recorded in Central California and tabulated here may be regarded as after-shocks of the megaseism of that date. Therefore, assuming the San Andreas fault as the sole generatrix of that shock, the great majority of these could be correlated with this fault alone. However, there are some grounds for thinking that other faults were concerned with the genesis of this great shock, even if only in an auxiliary sense; and there are even more grounds for considering that other faults may have been concerned in the generation of shocks afterward. A great part of California was shaken up, and earth strains presumably were unbalanced. Hence, in the correlation which follows, all the faults were taken into consideration and decision was made as well as possible in each case.

Report	Year	Date	Number	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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..	1906	April 19	..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	±	.	±	¡	±	.	¡	±	+
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REPORT	YEAR	DATE	NUMBER	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	13	14	15	16	11b	13b	17	16	18	19	20	21	22	23	24	25
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REPORT	YEAR	DATE	NUMBER	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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Report	Year	Date	Number	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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Report	Year	Date	Number	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	1c	14	15	16	11b	13b	17	1d	18	19	20	21	22	23	24	25
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REPORT	YEAR	DATE	NUMBER	1a	2	2	1b	3	4	5	6	7	8	9	10	11a	12	13a	13	14	15	16	11b	13b	17	16	18	19	20	21	22	23	24	25
..	1907	Jan. 4	..	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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..		Feb. 3	..	.	.	.	.	.	.	.	±	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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..		Mar. 11	..	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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..		Apr. 14	..	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
..		May 12	..	.	.	.	±	.	.	.	±	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
IV-V		June 5	..	.	.	.	±	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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END OF ASSEMBLED DATA

V. SUMMARIES AND CONCLUSIONS.

Analysis of these tables affords the following statistical results.

Between early in 1769 and the summer of 1907, an interval of a little over 50,000 days, earthquakes of Group I—comprising all whose intensities were estimated at V of the R.-F. scale, or greater—were *recorded* in California on some 678 dates; and on some 182 of these (exact numbers cannot be ascertained because of ambiguity and confusion, and incompleteness, in the records) there is mention of more than one shock—the number ranging from two, or larger specified numbers, up to more than one thousand in a single day. Often also a vague estimate is given, as "shocks," "several," "frequent," "many," etc.

When, on the date of a strong shock, there is mention of a large additional number, it is not to be considered that all were of intensity V R.-F. or greater, but only some of an associated series. Doubtless such a group usually is a swarm of after-shocks, and so an integral part of a single, major, seismic event. But to discriminate these instances in this tabulation would require far more intimate knowledge of the circumstances of their occurrence than the records afford. Moreover, on a great majority of the dates in question, from two to "several" independent shocks—of intensity V R.-F. or greater—are indicated.

Earthquakes of Group II—intensity estimated at less than V R.-F.—were recorded on nearly 1200 different dates. On about 275 of these there is mention of more than one shock, the number ranging from two up to one hundred or more shocks in a day; with also such vaguer enumerations as "several," "many," etc. As in the case of Group I, in a few instances these swarms probably are parts of a train of after-shocks, but usually not.

Of course it is true, inevitably, that in many instances earthquakes weaker than V are listed on the same dates as stronger shocks, so that the total of *recorded* shocks treated in this study occurred on less than 1800 days in more than 50,000.

Wherefore, considering together in one group all *recorded* earthquakes—both strong and weak, individual shocks and shocks in clusters—seismic disturbances have been *chronicled* in California on less than twelve days per annum in the interval from 1769 to 1907. Though it is sure that many more shocks have occurred on many more dates than those chronicled, still the *real* total need not breed alarm.

Let us now integrate the hypothetical fault-source distribution of these shocks on the basis of the foregoing tabulation.

In considering this integration the following condition must be kept in mind.

Nearly every earthquake has been correlated—under different degrees of probability—with more than one of the selected lines and faults, *and with segments of faults in many instances also.* (This latter procedure will account for some apparent numerical inconsistencies in the following table; where, for example, the shocks referred to the San Andreas fault as a whole have been enumerated independently—as have also those correlated with each of its segments.) Therefore most of the shocks are involved twice at least, many from three to six or seven times. Also in making the enumerations, when the words "shocks," "frequent," "many," "very many," "hundreds," etc., have appeared opposite earthquake events involved more than once, these words have been considered in the enumeration as often as the events were involved; though the number of such repetitions does appear in every case in the following integration table. Therefore all such groups are indicated too many times in the following table. (This, taken as a whole, thus lists more shocks several times over than have been recorded; but the table is not intended to be considered as a whole.)

In short, this table enumerates the sure, probable, ambiguous and doubtful occurrence of earthquakes upon each of the selected faults and lines, as determined in the foregoing correlation,—*without regard to corrected totals for the region as a whole.*

Table III, page 169, shows the result of the integration.

As explained in an early paragraph, the integration exhibited in the preceding table enables us to derive lower and upper limits for the probable *recorded* activity of each fault and line treated in the correlation.

For such faults and lines as prove to be actual earthquake sources the lower limits thus found are too low—and the upper limits too high—probably in every instance.

It is recognized that other faults, not yet discovered but closely neighboring to some of the faults or lines considered, may prove to be the actual sources. In such a case the statistics of probable occurrence very likely would undergo considerable apparent change—a matter of re-distribution; but even in such a case the general geographical-temporal result would not be affected in any marked way. And it is

TABLE III.

FAULT-SOURCE DISTRIBUTION OF TABULATED EARTHQUAKES.

FAULT-SOURCES	SURE, OR REASONABLY SURE *		VERY PROBABLE, OR PROBABLE +		AMBIGUOUS ±		DOUBTFUL ?	
	I	II	I	II	I	II	I	II
1 ind.	32 + very many	365+	222 + very many	101±	614 + hundreds	813 + very many	84 + hundreds	171 + many
1a	13 + very many	..	36+	4	114 + many	64 + several	9 + very many	5
1b	15 + very many	359±	137 + very many	61±	410 + very many	655 + many	88 + very many	80 + several
1c	6 + hundreds	4±	112 + very many	64	213 + very many	4	9	3
1d	6 + hundreds	..	49 + many	12±	87 + hundreds	31±	40 + hundreds	76±
2	..	..	90 + several	7	135 + many	248	56 + very many	..
3	..	..	1	..	33 + several	57	31±	..
4	..	..	12 + several	..	34 + many	74	54 + several	6
5	14 + many	..	43 + several	6	44±	38	9 + many	76
6	53 + many	..	129 + many	301 + several	258 + many	406 + many	150 + many	25 + several
7	..	..	1 ± many	..	23 + several	15	100 + several	137
8	..	..	..	..	12±	..	143 + many	9
9	..	..	12	..	28+	3	22 + many	13
10	..	..	1 + many	..	16+	11	178 + many	13
11ind.	..	..	6±	2	62± + several	53	18± + very many	8
11a	..	..	4	1	42 + several	34	9 + very many	8
11b	..	..	2	1	20 + several	19	9	..
12	134+	..	..	4	..	..	..	1
13 ind.	28 + 1000+	14	9±	4	879±	4	5±	5
13a			2	1	1	4	3	..
13b	28 + 1000+	14	7	3	878	..	2	5
14	..	..	..	..	6	1	155+	11
15	..	..	..	..	..	2	41+	6
16	..	..	1	..	33 + many	20	44 + several	32
17	..	..	876±	..	..	..	2	..
18	..	..	12 + many	11	37 + many	27	33 + hundreds	5
19	..	..	12 + several	4	56 + hundreds	76	60 + very many	9
20	..	..	1	..	6	..	31 + hundreds	45
21	..	..	38 + hundreds	5	48 + hundreds	110	29 + very many	41 + several
22	..	..	..	..	1	..	18 + hundreds	40 + several
23	..	..	..	..	14 + many	..	52 + very many	90
24	..	..	22	1	88 + hundreds	134	18 + hundreds	13
25	13 + many	4	32 + hundreds	50	87 + hundreds	145	19±	6

conceivable that no significant changes in fault-source distribution would result—merely changes of name, and small changes in position, of the fault-sources.

However, it is this contingency which lays emphasis upon the greatest weakness in the correlation—that which inheres in the doubt as to the probable activity of lesser recognized faults which are situated near to the greater known generatrices, particularly when these have parallel courses.

Only seismometric investigations conducted at a sufficient number of suitably distributed stations can resolve the doubts in such circumstances; except that from time to time the occurrence of strong earthquakes may decide such questions locally by bringing specific geological conditions to view; or very rarely the distribution of intensity, or of time of onset, may be sufficiently well observed for such a purpose in restricted localities thickly populated. Of course such accidental and sporadic determinations have only slight value in a systematic attack upon the problem.

The table of limits of probable fault-source occurrence appears on the opposite page.

This table of limits is an important goal of the correlation. It enables us to compare directly the statistical probability of action on the faults treated, with our knowledge of the geological character of the districts they traverse, of the past distribution of population, and the state of the record.

We have geological and historical knowledge of the actual seismic activity of 1 (the San Andreas fault), 6 (the Haywards fault), 13 (the Major Sierra fault-system), 18 (the Santa Ynez fault—or some neighboring fault or system of faults), and 25 (the San Jacinto fault); also almost undoubtedly 12 (the Honey Lake fault-zone) and 17 (the Kern fault). Though the judgments involved in the correlation are not wholly independent of this knowledge, still they are so numerous, and so great a variety of circumstances is involved, that their sum also amounts practically to a demonstration of action on these faults.

The apparent superior activity of 1*b* and 1*c* over 1*a* and 1*d* may be actual, or more probably it may be due to the state of the record. Also it must be remembered that 1*a* possibly does not belong to the San Andreas zone.

No further comment on 6 is needed.

Both 13*a* and 13*b* traverse a piedmont country which has been

TABLE IV—LIMITS OF PROBABLE FAULT-SOURCE OCCURRENCE

GENERATRICES	UPPER AND LOWER LIMITS OF RECORDED SHOCK-OCCURRENCES UPON GENERATRICES TREATED					
	LOWER LIMITS			UPPER LIMITS		
	I	II	ALL	I	II	ALL
	* +	* +	* +	* + ± ?	* + ± ?	* + ± ?
1 ind.	254 + very many	466+	720 + very many	952 + hundreds	1450 + very many	2402 + hundreds
1a	49 + very many	4	53 + very many	172 + very many	73 + several	245 + very many
1b	152 + very many	420±	572 + very many	656 + very many	1155 + many	1811 + very many
1c	118 + hundreds	68±	186 + hundreds	340 + hundreds	75+	415 + hundreds
1d	55 + hundreds	12±	67 + hundreds	182 + hundreds	119±	301 + hundreds
2	90 + several	7	97 + several	281 + very many	255	1036 + many
3	1	..	1	65±	57	122±
4	12 + several	..	12 + several	100 + many	80	180 ± many
5	57 + many	6	63 + many	110 + many	120	230 + many
6	182 + many	301 + several	483 + many	590 + many	732 + many	1322 + many
7	1 ± many	..	1 ± many	124 + many	152 + several	276 + many
8	..	..	..	155 + many	9	164 + many
9	12	..	12	62 + many	16	78 + many
10	1 + many	..	1 + many	195 + many	24	219 + many
11 ind.	6±	2	8±	86 + very many	63	149 + very many
11a	4	1	5	55 + very many	43	98 + very many
11b	2	1	3	31 + several	20	51 + several
12	134+	4	138+	134+	5	139+
13 ind.	37 + 1000 +	18	55 + 1000 +	921 + 1000 +	27	948 + 1000 +
13a	2	1	3	6	5	11
13b	35 + 1000 +	17	52 + 1000 +	915 + 1000 +	22	937 + 1000 +
14	..	..	..	161+	12	173+
15	..	..	..	41+	8	49+
16	1	..	1	78 + many	53	131 + many
17	876±	..	876±	878±	..	878±
18	12 + many	11	23 + many	82 + hundreds	43	125 + hundreds
19	12 + several	4	16 + several	128 + hundreds	89	217 + hundreds
20	1	..	1	38 + hundreds	45	83 + hundreds
21	38 + hundreds	5	43 + hundreds	115 + hundreds	156 + several	271 + hundreds
22	..	..	..	19 + hundreds	40 + several	59 + hundreds
23	..	..	..	66 + very many	90	156 + very many
24	22	1	23	118 + hundreds	148	266 + hundreds
25	45 + hundreds	54	99 + hundreds	151 + hundreds	205	356 + hundreds

and is little occupied. Probably there is little to choose between them in the matter of the record. Both the recorded activity and the geological aspect suggest very strongly that more frequent and more energetic fault-slipping is in progress along the southern segment, 13*b*.

With regard to 18 the writer is in doubt. If it were profitable to revise the whole study, a fault-system would be substituted for the specified fault chosen. However, a seismic source, or sources, undoubtedly exists in this district apart from 1*c* and 16.[23]

In all probability the record for 25, though in some instances quite definite, is very incomplete.

The activity of 12 seems to be indicated satisfactorily, but the record must be very incomplete.

Proof of activity of 17 rests upon a single event which, however, seems definite. Only a major event upon this fault was likely to be recorded. The geological aspect is favorable to such an indication.

The grand totals for the upper limits indicate that none of the lines or faults treated can be neglected, until our knowledge is extended further.

However, it is an obvious conclusion that the correlation does not establish any strong probability of action on 3 (the Mount St. Helena fault), 8 (the San Gregorio fault), 10 (the Pajaro fault), 14 (the Santa Lucia fault), 15 (the Templeton fault), 16 (the San Luis Obispo fault), 20 (the Santa Monica fault), 22 (the Whittier fault), and 23 (the Santa Ana fault). It is fair to add that there are geological reasons for *suspecting* some of these of activity.

The indication of action on 4 (the Suisun fault) is rather weak. However, if this fault can be traced northward beyond its present known extension, the probability of its activity would be much increased. But it is not unlikely that a *system* of faults will come to light here instead of a continuous zone of rifting.

The shocks of July 3-4, 1861, make it necessary to look upon 7 (the Sunol fault-system) as a probable generatrix. Were it not for this event its activity would be wholly ambiguous, owing to its proximity to and its parallelism with 6 (the Haywards fault), and to the fact that it passes through an intermontane district scantily peopled, especially in the early years.

Little can be said of 19 (the San Gabriel fault) and 24 (the Elsinore fault). Fair judgments indicate them rather weakly, but decidedly they cannot be classed with the less probable group. Events have never demonstrated their activity.

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[23] Cf. Beal, C. H., *Bulletin Seismological Society of America*, 5, 14-25.

This brings us to a review of lines, or hypothetical fault-systems.

That 2 (the Eureka–Ukiah–San Pablo line) traverses a district in which there are actual lines, or systems, of "living" faulting is now known, though the minutiae have not been worked out. This fact was indicated very forcibly by the tabulation before any of the fault-courses were found.

5 (the Mare Island–Nevada–Carson line) is so strongly indicated that there seems little doubt of a deep fault-system aligned along this general belt. Strict proof of this, if asked for, cannot be given; but the writer thinks that the shocks of April 1892 may nevertheless be regarded almost as a demonstration, though there was no fault-outcrop at the surface. The strong indication of this generatrix and of frequent and energetic action upon it,—together with the action upon 13*b* (especially in contrast to 13*a*), and the physiographic development of the Southern Sierra,—is consistent with the hypothesis of relatively rapid tilting of the South Sierran crust-block to the west and north.

The *correlation* does not greatly strengthen the hypothesis of the existence of 9 (the Monterey Submarine fault-zone), but certain shocks in this region have surely originated beneath the sea. The problem thus raised must await future solution through seismometric origin-surveys, sporadic eventualities, or ways at present unknown.

11 (the Great Valley axis) is merely a catch-all for shocks recorded at localities scattered throughout this large basin which cannot be referred to the faults and lines worked with. Hence the occurrences associated with this line point to undiscovered faults which must be sought for. That such exist the study indicates forcibly, but there is no suggestion that frequent or energetic action on them is to be expected. Consequently seismometric origin-survey is most likely to accomplish their discovery.

The correlation does greatly strengthen the hypothesis that 21 (the San Pedro Submarine fault-zone) exists, though real proof is wanting. The location, courses, and extent of the faults involved await seismometric determination.

Besides the earthquakes assigned to known and to hypothetical generatrices, shocks of Group I occurred on 22 dates and shocks of Group II on 38 dates, which could not reasonably be referred to any of the faults or lines under consideration (or to any faults or lines known or suggested to the writer). These facts, like the study as a whole, point to the necessity of establishing in this region a scientific institution charged with the investigation of earthquake sources, and their behavior, by means of the most approved field and laboratory methods and facilities.

This study also leads to comment on certain other aspects of seismicity in California.

In the introduction to his catalog Holden discussed—as well as the data permitted—the annual and seasonal occurrence of shocks down to 1887, for the entire region (including a few shocks recorded in Oregon and Washington), for San Francisco, and for San Jose. The conclusions deduced were somewhat contradictory. The body of data is so incomplete and so imperfect that it seems inutile to attempt an extension of this work.[24]

As good data become available, correlation of shocks with rainfall within definite meteorological provinces is a desideratum, since both statistics and the rationale appear to indicate greater seismic frequency in the wet season in many parts of the world.

Correlation of shocks of intensity VI or greater of the Rossi-Forel scale—when not obvious after-shocks of some great seismic event—with the maxima of declination of the sun,[24] and moon, probably will develop interesting results; but accurate and voluminous records, without significant lacunae, are needed for this.

In certain instances the writer has deemed it advisable, as mentioned earlier, to revise the estimates of intensity given by Holden, McAdie, and others, in the light of newer knowledge. Usually the later estimate is somewhat higher than the earlier. This makes desirable a revision and expanded treatment of the geographical and temporal occurrence of two groups of stronger seismic events: (1) those of intensity IX-X R.-F., and (2) those of intensity VI-VIII R.-F. The maxima of the first group may be considered potentially (if not actually) disastrous, those of the second alarming to slightly destructive.

While the events included in the more energetic group have differed widely in the total energy developed, and in the number of strong shocks comprised in the whole seismic event (though usually there has been one chief shock), all have been strong enough in an epifocal area of greater or less extent to have produced damage or disaster under ordinary urban conditions. It does not matter that these strong districts often have been far from cities. The energy has been available.

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[24] Cf. also Spalding, W. A., *Bulletin Seismological Society of America*, 5, 31-38.

The occurrence in these groups is shown in the following Table V, in which the lettered columns denote sub-provinces, as follows: A, the Northern Coast province; B, the Central Coast province; C, the South-Central Coast province; D, the South Coast and Mountain province; E, the Sierran escarpment and Piedmont belt, and F, the Mare Island–Nevada–Carson belt. The province of the Great Valley is neglected. Numbers marked with an asterisk (*) refer to shocks counted in more than one province.

The temporal-geographical occurrence-distribution is grasped more easily from the diagram, Figure 2, on which abscissas show the time by years from 1769 to 1907; and ordinates, drawn as solid and as broken lines, show the number of the seismic events per year for each sub-province, the sub-provinces being designated by the letters A-F, as in Table V. Solid-line ordinates show the number of such events in given years which were confined wholly, as to cause, to the given sub-province. Broken-line ordinates show the number of events in given years which appear to have belonged to more than one sub-province. *It must be noted that solid and broken ordinates are drawn in side-to-side contact* for a considerable number of years—to indicate the occurrence of both sorts of shock in the same year. For example, in sub-province B in 1891 there were six shocks of the lesser group confined wholly to this sub-province, and three shocks, also of the lesser group, which affected both this and other sub-provinces as well —a total of nine shocks of the lesser group in this sub-province in 1891.

Previous to 1850 the records are too sparse to permit of any deductions.

Beginning with 1850 no events of either group were recorded in any part of the California region in the following years: 1850, 1866, 1874, 1876, 1879-80-81, and 1886.

The interval 1879-81 is noteworthy. It falls in the middle of a group of ten to fifteen years in which comparatively few strong earthquake events occurred in any part of this region. This interval of lessened activity followed a group of years, 1855-72, in which strong to very strong seismic crises occurred in rapid succession throughout the entire region. The interval of comparative quiet was succeeded by a sequence of years characterized by numerous strong shocks in

TABLE V.

GEOGRAPHICAL-TEMPORAL DISTRIBUTION OF STRONGER SEISMIC EVENTS

DATES	INTENSITY IX.-X. R.-F.						INTENSITY VI.-VIII. R.-F.					
	A	B	C	D	E	F	A	B	C	D	E	F
1769	. .	. .	. .	1	. .	. .	. .	. .	. .	. .	. .	. .
1790?	. .	. .	. .	. .	1	. .	. .	. .	. .	. .	. .	. .
1800	. .	. .	. .	. .	. .	. .	. .	1+	. .	. .	. .	. .
1803	. .	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .
1806	. .	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .
1808	. .	. .	. .	. .	. .	. .	. .	1+	. .	. .	. .	. .
1812	.	1(?)	. .	1	. .	. .	. .	. .	. .	1+	. .	. .
1813 } 1815 }	.	1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1818	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .	. .
1829	. .	. .	. .	. .	. .	. .	. .	1+	. .	. .	. .	. .
1830	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .
1836	. .	1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1838	. .	. .	. .	. .	. .	. .	. .	1+	. .	. .	. .	. .
1839	. .	1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1840	. .	1•	1•	. .	. .	. .	. .	. .	. .	. .	. .	. .
1841	. .	. .	. .	. .	. .	. .	. .	1•	1•	. .	. .	. .
1843	. .	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .
1851	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .	. .
1852	. .	. .	2•	2•+1	. .	. .	. .	1	. .	. .	. .	. .
1853	1	. .	1•	1+1•	. .	. .	. .	. .	. .	. .	. .	. .
1854	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .	. .
1855	. .	. .	. .	1	. .	. .	. .	2	. .	. .	1•	1•(?)
1856	. .	. .	1•(?)	1•(?)	. .	. .	. .	2	. .	2	. .	. .
1857	. .	. .	1•	1•	. .	. .	1	1+2•	1+3•	1+3•	. .	. .
1858	. .	1	. .	. .	. .	. .	. .	2	. .	. .	. .	. .
1859	. .	. .	. .	. .	. .	. .	. .	4	. .	. .	. .	. .
1860	. .	. .	. .	. .	. .	1	. .	1+2*	1*	1–2	. .	1*
1861	. .	1	. .	. .	. .	. .	. .	1•	. .	. .	1•	1•
1862	. .	. .	. .	. .	. .	. .	. .	1+1•	. .	2	1•	1•

1863	..	..	..	..	..	..	..	3	..	1	..	..
1864	..	..	..	..	..	..	..	1+5•	3•	..	..	2•
1865	1+1•(?)	1•	1•	..	..	..	2+1•	1+1•	..	1	..	1(?)
1867	..	..	..	..	..	..	..	2•	..	..	..	2•
1868	..	1•	1•	1	2±	1•(?)	2	2+1•	1+1•	..	..	1(?)
1869	..	..	..	..	..	1	1	1•	1	..	..	1•
1870	..	..	..	..	..	..	..	1	..	..	..	..
1871	1	..	..	..	..	..	..	..	..	..	2	..
1872	..	..	..	..	1	..	..	..	..	..	5+	..
1873	..	..	..	1	..	..	..	1	..	..	..	..
1875	..	..	..	..	..	..	..	1•	..	1	..	1•
1877	..	..	..	..	..	..	..	..	..	1	..	..
1878	..	..	..	..	..	..	2	..	..	..	..	..
1882	..	..	..	..	..	..	..	..	..	..	1	..
1883	..	..	..	..	..	..	1	2•	2•	1	..	1
1884	..	..	..	..	..	..	1	1•	1•	..	..	1•
1885	..	..	..	..	1	..	..	4	..	..	..	..
1887	..	..	..	..	.	..	1+2•	3+2•	..	..	..	1(?)
1888	..	1•	..	..	..	1•	2*	4+3*	2*	1+1•	..	1•
1889	..	..	..	..	1	..	..	3+1•	..	3	1	1•
1890	..	1•	1•	..	1	..	..	4	1•	3+1•	1(?)	..
1891	..	..	..	..	..	..	2•	6+3•	1•	..	1	2•
1892	..	1•	..	1	..	1•	..	2+1•	1•	3	1	..
1893	..	..	..	1•	1•	..	3	4+2•	1•	3	..	1(?)+1•
1894	..	..	..	..	..	..	1	..	..	4+1•	1(?)+1•	3(?)
1895	..	..	..	..	..	..	1+1*	2*	..	..	1	1*
1896	..	..	..	..	..	..	1	1	..	1	..	1(?)
1897	..	1•	1•	..	..	..	1+1*	1+1*	..	1	..	1(?)
1898	1•	1+1•	..	..	..	1*	3+1•	1•	1•	1•	..	..
1899	..	..	..	1	..	..	1	..	..	..	..	..
1900	..	..	..	..	..	..	..	1+1•	..	..	..	1•
1901	..	..	..	..	..	..	..	1•	1•	..	..	..
1902	..	..	..	1	..	..	..	1•	..	2	..	1•
1903	..	..	..	..	..	..	1	1+2•	1•	4	..	2•
1904	..	..	..	..	..	..	1+1•	1+1•	..	..	..	..
1905	..	..	..	..	..	..	..	..	1•	1+1•	..	..
1906	1•	1•	1•	1	..	..	2+(1+2*)§	(2+4•)§	(3•)§	..	..	..
1907	..	..	..	..	..	..	..	1	..	..	..	..

§ Aftershocks ¶

all parts of California,—though no so-called great earthquake happened until 1906.

This apparent occurrence in periods is highly interesting; but the data are not adequate for the discussion and testing of hypotheses. Nevertheless, a periodic variation in occurrence seems fairly well indicated in sub-provinces B and D, which are the regions of most complete and most reliable records. Seismic causes are of so complex nature that no sharply defined periods can be expected.

It is well known that great, world-shaking earthquakes are followed by an irregular train of numerous after-shocks. Almost always such an event is preceded by a sequence of fore-shocks as well,—though these are rarely sufficiently well characterized by the circumstances and sequence of their occurrence to serve for prediction. The days and months, sometimes the years also, before and after a megaseism are, however, periods of greater seismic activity than normal.

This has been true in California as in other lands; but it has been so difficult to discriminate the shocks of these families from those presumably quite independent, on the basis of the available data, that no cognizance was taken of these two categories in the correlation, and no discussion of such genetic groups can be undertaken here. To illustrate how imperfect the data may be: the writer has been told that more than 120 shocks were counted in the month of November 1905 in the Richmond district in San Francisco; also that no day passed in April 1905 without a shock being felt in this city. These statements were based on memory, but seem reliable for all that. But the catalog gives no hint, even, of such frequency.

In fine, this study, despite its weaknesses and uncertainties, illumines the seismic problem in California. It raises genetic questions—and questions of mechanism. It throws into bold relief geologic and geographic questions in the seismology of the province; and points to profitable directions, and ways, of attack upon these for determining loci of origin, and discovering the development and areal control of phenomena depending upon intensity. It shadows forth the geographical-chronological occurrence of strong seismic events, and vaguely develops its significance. It holds out the hope of prediction of sorts, though as yet not of precise time-prediction. It indicates clearly the need for various field studies, seismometric research, and allied laboratory studies, and various statistical treatments and analyses, to clarify and extend our knowledge of earthquake occurrence in this region. Great and far-reaching generalizations in geophysical

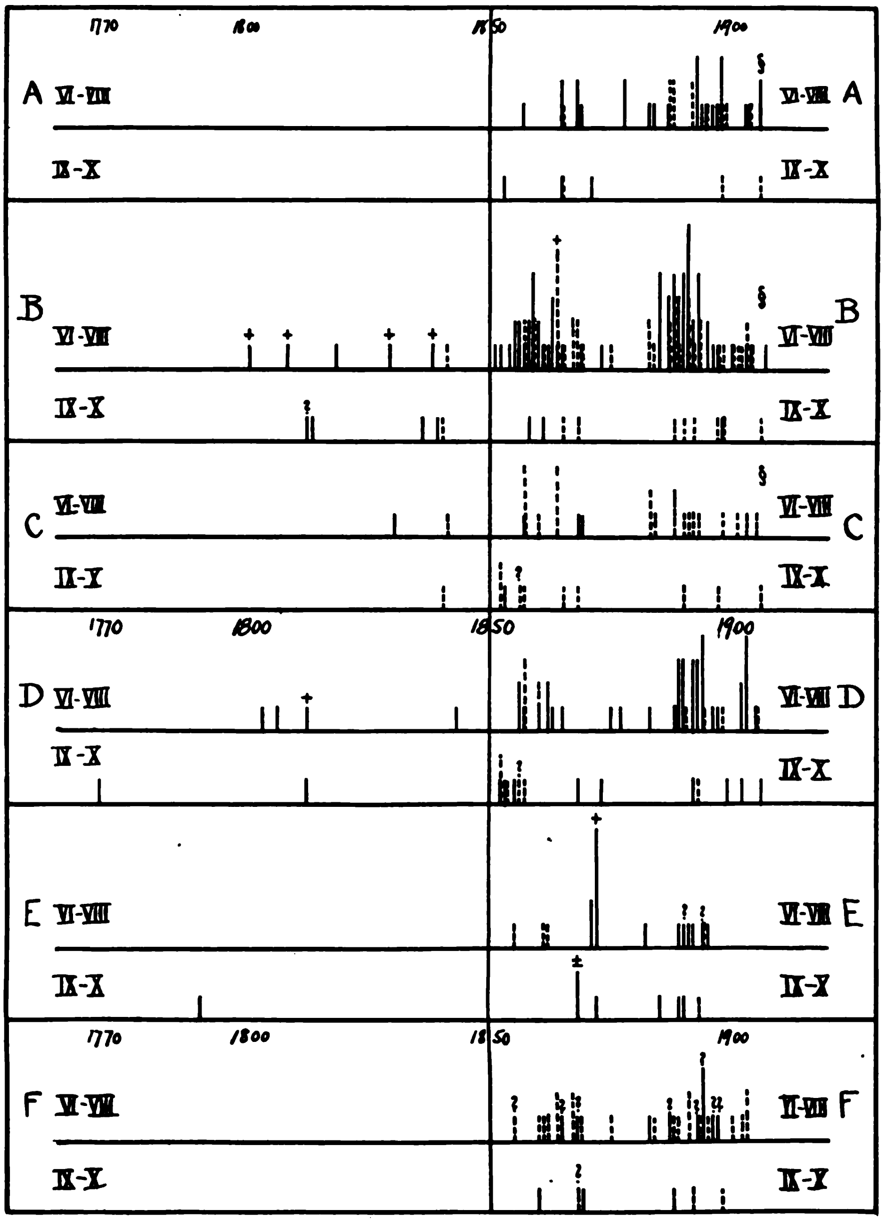


Fig. 2.

science must eventually result from a thorough and vigorous program of research along these lines; while from the social and humanitarian standpoint alone, the frequency and character of the earthquakes recorded hitherto, considered in the light of their undoubted origin and of the geologic history of the region, make superfluous further comment upon the necessity of initiating systematic and comprehensive seismologic investigation here. In the early stages of such work the suggestions of this study should prove of value.

May 18, 1916.

THE EARTHQUAKE AT VOLCANO LAKE, MEXICO, NOVEMBER 20, 1915.

The *Bulletin of the Seismological Society of America* for September 1915 (Vol. 5, no. 3, pages 130-149) contained an article upon the earthquake in the Imperial Valley, California, June 22, 1915, by Carl H. Beal. In his field studies Mr. Beal went as far south as Volcano Lake in Mexico, and the map accompanying his article shows the location of that lake. Mr. Beal believes that the southward extension of the San Jacinto fault passes through the mud volcanoes and along the western margin of Volcano Lake, and he so represented it. The map is reproduced here as Fig. 1.

Through the kindness of Mr. F. C. Hermann, civil engineer, it was learned that another earthquake was felt in the Imperial Valley November 20, 1915, and that it was especially severe at and about Volcano Lake, twenty-five miles south of Calexico, the town at the California-Mexico border.

It has not been possible to have a field study made of this particular earthquake, and in view of the fact that the region near the lake is almost without inhabitants, it does not seem probable that much information could be added, by such a study, to what has been learned from the interesting letters of Mr. W. J. Best, civil engineer and Superintendent of the Mexican Irrigation Company, and of Mr. C. N. Perry, county surveyor of Imperial County, California, both of which are given here. Following is a copy of part of a letter from W. J. Best to F. C. Hermann, at San Francisco, and dated Calexico, Cal., July 10, 1916:

> On the afternoon of November 20, 1915, Thos. Fleshner and I went to the Volcano Lake region on a duck and quail shoot. We stopped about two miles north of the lake to shoot a few quail that were in sight, and were doing finely until the earthquake came, which was the most violent quake either of us had ever experienced. The wave-motion seemed to be from south to north, with the exception of one violent shock which seemed to come from the east. This one very nearly got us down, though we were on perfectly smooth ground and trying to keep our balance. After getting straightened up I

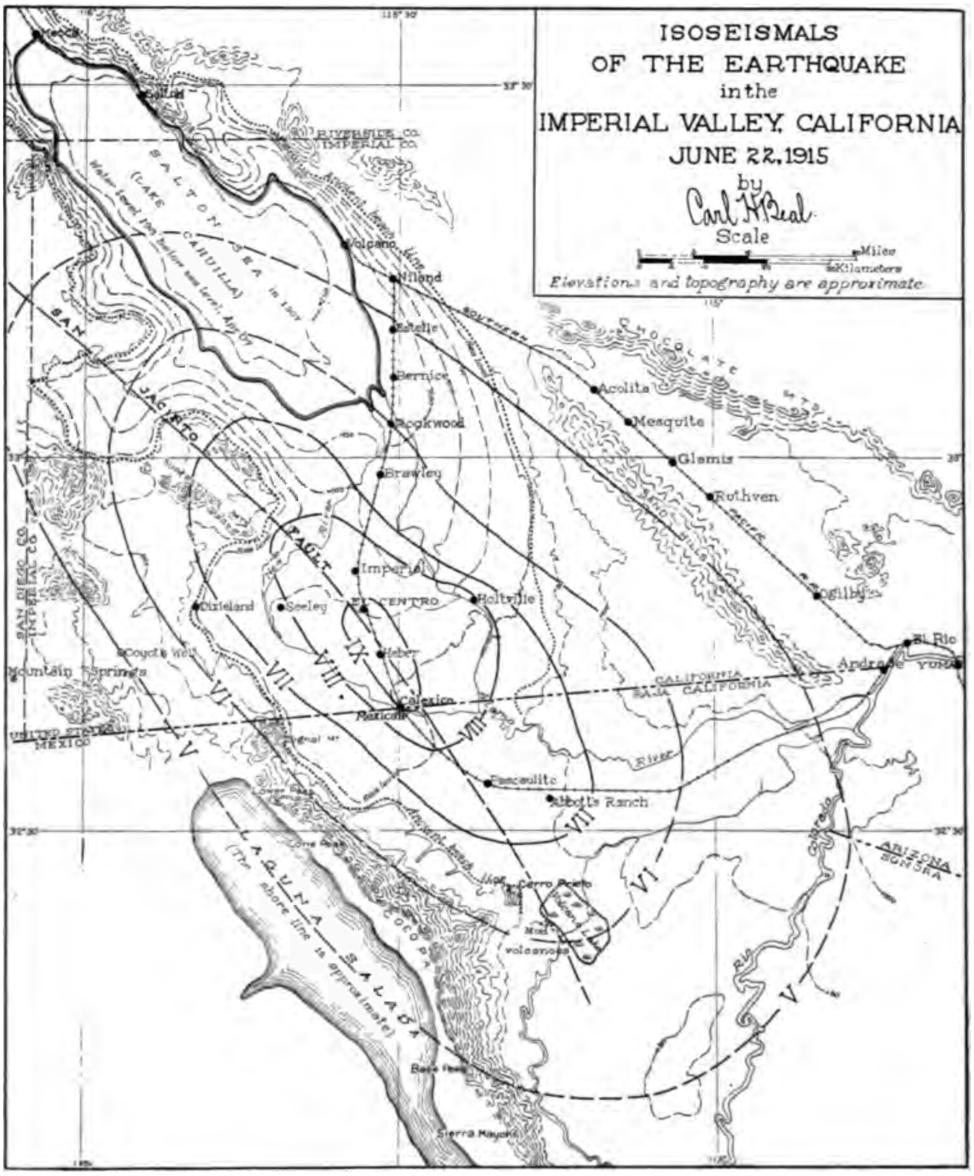

ISOSEISMALS
OF THE EARTHQUAKE
in the
IMPERIAL VALLEY, CALIFORNIA
JUNE 22, 1915
by
Carl H. Beal
Scale
Miles
Kilometers
Elevations and topography are approximate
SALTON SEA in 1907
(LAKE CAHUILLA)
SAN JACINTO FAULT
RIVERSIDE CO.
IMPERIAL CO.
SAN DIEGO CO.
IMPERIAL CO.
Volcano
Niland
Estelle
Bernice
Brookwood
Brawley
Imperial
EL CENTRO
Holtville
Dixieland
Seeley
Heber
Calexico
Mexicali
Coyote Well
Mountain Springs
CHOCOLATE MTS.
Acolita
Mesquite
Glamis
Rothven
Ogilby
El Rio
Andrade
YUMA
CALIFORNIA
BAJA CALIFORNIA
UNITED STATES
MEXICO
ARIZONA
SONORA
Pascualitos
Abbotts Ranch
Cerro Prieto
Mud volcanoes
COCOPA
LAGUNA SALADA
(The shore line is approximate)
Sierra Mayor
Colorado
River
Ancient beach line
IX
VIII
VII
VI
V

Fig. 1.

looked at my watch, noting that it was 4:15 p.m., and remarking at the same time that if the quake continued down the (Imperial) valley with the same force it had there, that there would not be a building standing when we got back. At about this time our attention was attracted by a gusher which appeared to be in Volcano Lake. On arriving at Station "O," at the extreme west end of Volcano Lake levee, we had a very beautiful view, being about two miles from the gusher, which by this time had reached the cloudline and had formed an immense cloud above it. The sun shining on this made it a very beautiful sight to see and one that is hard for me to describe; but it resembled an enormous snowbank balanced on a coal-black pedestal, which was silvery lined on the edge where the sun was shining on it, and the cloud was continually changing its shape. At this time we thought the diameter of the gusher was about fifty feet; but three weeks later three others and I worked our way by boat to where the gusher had been, and instead of finding a fifty-foot crater we found one between four hundred and five hundred feet in diameter.

I did not find any cracks, other than those on the levee in dry ground; and where the levee cracked, the ground on each side of the levee was damp. Cracks were noticeable on both sides of New River for a distance of two miles, but that also appeared to be in damp earth.

There are no houses in that vicinity. The shock was felt at the Abbott ranch and the Pascualitas ranch, and also over the entire Imperial Valley. I have talked to one or two persons from Yuma and they claim that the shock of November 20th was much greater there than the one they had in June at the time the damage was done in Imperial Valley.

I judge from what little I know of earthquakes that the most violent shock must have been in the lake and south of the lake. Toney Manser, range foreman for the C-M Cattle Company, and whose duty it is to ride over the country south and east of the lake, told me recently that it would be impossible for a certain channel to scour out what is known as the Pasquedor River, as the November earthquake had caused a sliding of the banks on both sides into the river, and, the banks being covered with a dense growth of large willow and cottonwood trees, they had made a good job of riprapping for several miles. This leads me to believe that the most violent shock was either in the lake or south of it, between the lake and Gulf, although some Mexicans reported that some springs that are over on the Sonora side of the Colorado River dry channel were very active at that time.

Another thing which may be of some value is the fact that the Volcano Lake as a whole and the country south of what was once the lake has been silted up to a depth ranging from four to ten feet, and covering an area of twenty square miles or thereabouts.

The levee height was an average of eleven feet, having a two-to-one slope on the water side and a four-to-one slope on the land side.

The photograph taken at Station "O" (Fig. 3) shows the Cocopah Range, which is west of the lake some seven or eight miles. The reservoir is on the southern side of the levee.

Mr. C. N. Perry, county surveyor of Imperial County, California, was at Calexico, California, at the time of this earthquake. On December 14, 1915, he wrote from El Centro, California, as follows:

> We had another earthquake here November 20th; the first shock occurred at 4:35 p.m., followed by another at 8:10 p.m.
>
> Here in the Imperial Valley towns it took the form of an easy swaying motion, not a jolt nor jar; and absolutely no effect was produced even on buildings undergoing repairs.
>
> At Volcano Lake and vicinity the story was different. The first shock happened when I was in Calexico; the second came when I was camped one mile north of the Volcano Lake levee and at the foot of the Black Butte or Cerro Prieto. That shock was violent.
>
> I had arranged with two friends, Mr. W. J. Best and Mr. Thos. Fleshner, to go to Volcano Lake that afternoon, but stayed behind at Calexico to witness a football game between two of our high schools. The other two, however, were at Volcano Lake during both shocks. They described the first shock as being much more violent than the second. Immediately after the first shock one of the volcanoes became active and according to their story sent up a column of steam 600 or 700 feet high, immediately followed by a column of black mud, which they say reached approximately the same height; and for an hour afterwards, or until the sun set, they watched this column alternating between steam and mud.
>
> I reached there about 6:30 p.m., and from that time until about 8:30 the column of steam could be plainly seen by the light of the full moon.
>
> I understand that this shock was rather strong in San Diego and Yuma. It was felt in a slight degree in Los Angeles. A friend who was up in the tenth story of a building in Los Angeles described it to me as being anything but pleasant.
>
> A Mexican living at the east end of the Volcano Lake levee described the shock as very light. I have not had a chance to determine the question definitely, but my impression now is that a very large area, say ten square miles, of the country adjacent to the volcanoes, has sunk appreciably. My only justification for this idea is the amount of country covered with water at this stage of the Colorado (River). I may be mistaken, however.

The accompanying photographs show the character of the cracks made on the flanks of the levee. Mr. Beal observes that the San Jacinto fault passes about half way between Cerro Prieto and the point from which the first pair of photographs was taken.

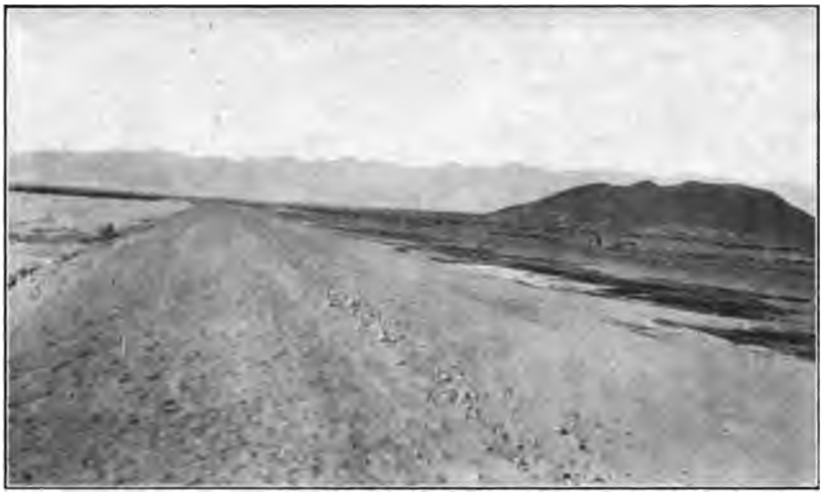


Fig. 2. Volcano Lake levee looking west and showing Cerro Prieto or Black Butte, an extinct volcano, on the right, and the Cocopah Mountains in the background. Taken August 4, 1915, by C. H. Beal.

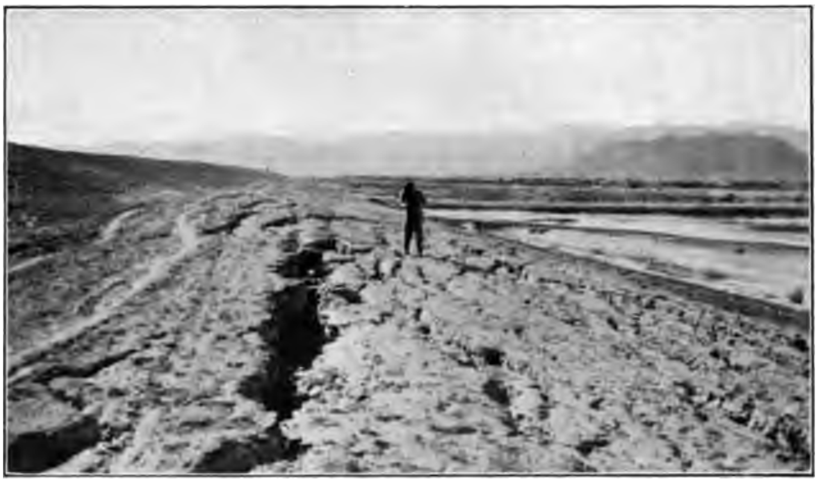


Fig. 3. Taken near same place as figure 2, but just below top of levee, after the earthquake of November 20, 1915.

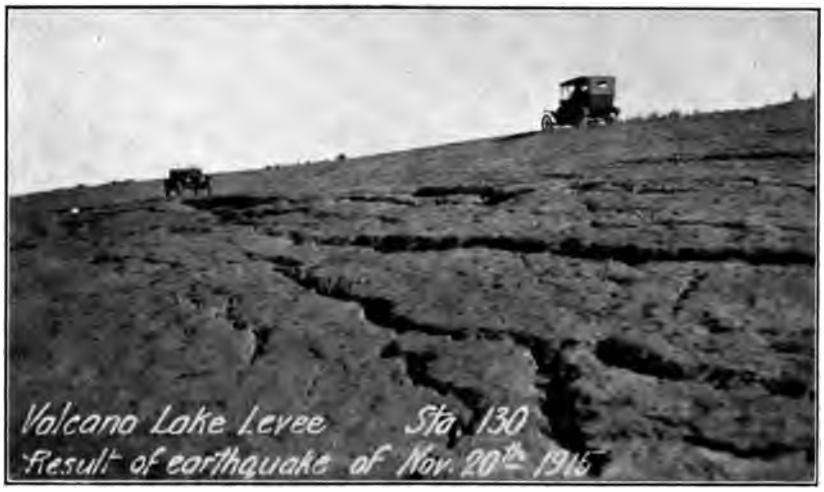

Volcano Lake Levee Sta. 130
Result of earthquake of Nov. 20th 1915

Fig. 4.

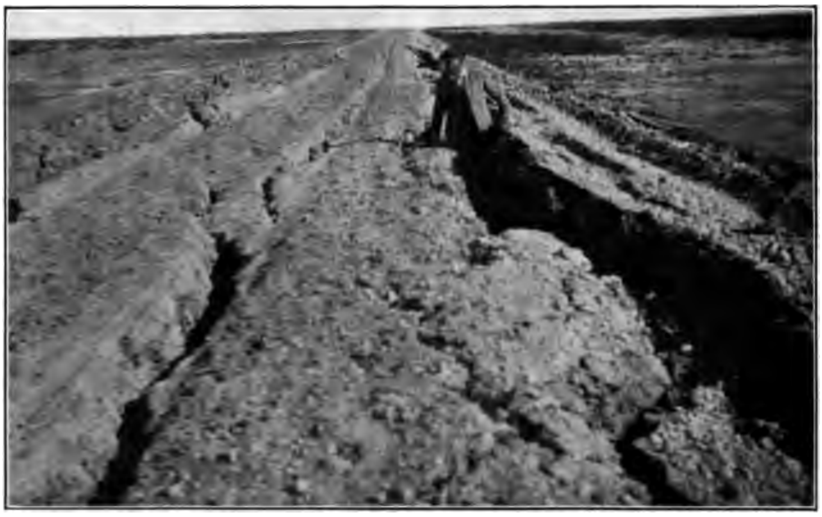


Fig. 5. Cracks in Volcano Lake levee made by the earthquake of November 20, 1915.

SEISMOLOGICAL NOTES

The death is announced of Prince Boris Galitzin, the distinguished Russian seismologist and professor of physics at the Academy of Sciences at Petrograd. He was born at St. Petersburg in 1862.

Santo Domingo, April 23, 1916.—A severe shock was reported from Santo Domingo at 11:30 p.m., but without serious damage. This shock was recorded at the Georgetown University station, Washington, D. C.

San Juan, Porto Rico, April 24, 1916.—At 12:30 a.m. a severe shock was felt at San Juan, but no serious damage was done. This shock was also recorded at the Georgetown University station, Washington, D. C.

Boise, Idaho, April 29, 1916.—A distinct shock was felt at Boise, Idaho, at 8:18 p.m.; no damage was done.

Costa Rica, May 1, 1916.—It was reported from San Jose de Costa Rica that twenty distinct earthquake shocks were felt at that place on May 1st. Churches and school buildings were thrown down and the people fled into the streets.

Canary Islands, May, 1916.—Earthquakes were felt in the Canary Islands in the early part of May, but it has not been possible to learn anything of the details further than that no one was killed.

Claremont, Cal., May 2, 1916.—Professor C. C. Kiess of Pomona College reports that an earthquake with an intensity of IV R. F. scale was felt at Claremont, Cal., May 2, 1916. He says there were two distinct jolts separated by about five seconds, and followed by tremors lasting approximately twelve seconds. The time was 6:31 a.m., Pacific Standard time, and is not in error by more than ten seconds.

Boise, Idaho, May 12, 1916.—The following account is condensed from the newspaper reports of an earthquake felt at Boise, Idaho, May 12th at 7:26 p.m.: The tremor lasted only about three seconds, but it was the most violent shock ever experienced at Boise, and it was felt over a large part of the surrounding country and in eastern

Oregon and western Montana. At Weiser, sixty miles southwest of Boise, the shock was also strong, and caused a great increase of flow from a natural gas well at that place.

Rimini, Italy, May 16-17, 1916.—Earthquakes are reported in central Italy on May 16 and 17, 1916, but no details have been learned up to the present. At Rimini on the Adriatic coast, a hundred miles north of Venice, the shock is said to have been especially violent. A dozen persons are reported injured at Cesena, a little town about fifteen miles west of Rimini.

Mauna Loa in Eruption.—The Hawaiian volcano Mauna Loa began to erupt in the early part of May, 1916, and the lava began to rise in Kilauea about the same time.

San Diego, Cal., May 27, 1916.—A slight earthquake was felt at San Diego, Cal., at 9 o'clock, May 27, 1916.

Forli, Italy, June 16, 1916.— At 3:25 a.m., June 16, 1916, a heavy earthquake is said to have occurred in the region between Forli and Rimini, about fifty miles south of the mouth of the Po. No serious damage is reported.

Ferndale, Cal., July 4, 1916.—An earthquake of unusual violence occurred at Ferndale, Humboldt county, California, July 4, 1916, at about 8:45 p.m. The shock lasted several seconds. Trees swayed as if blown by a violent wind, vases were thrown from shelves, and a plate-glass window was broken. Some persons report that the shock was preceded by a distinct roaring sound. These facts were reported to Dr. J. P. Smith by Mr. H. W. Underhill of Ferndale.

Additional information was kindly furnished by Miss Mildred Smith, who was about two miles west of Ferndale at the time of the shock. She says it occurred about 8:45 p.m., that it lasted only a few seconds, and that the shock was more violent at that place than at Ferndale, while in some places it was hardly noticed. In the house where she was there was a jingle like glass breaking, caused by the knocking down of some bottles and a box of brass fishing-spoons, and there was an awful crash made by the throwing down of wood that had been piled up in a wood-shed. The cream from milk-pans was spilled over the dairy floor, and "both our chimneys and D—'s were cracked, but didn't fall. The wall-paper on a wall facing west wrinkled first in one way and then the other."

At Eureka, about seventeen miles further north, three distinct shocks were noted, the first and severest one at 8:39 p.m.

Stromboli, Italy, July 3-4, 1916.—The volcanic island of Stromboli, about forty-five miles north of Messina, broke into violent eruption July 3, 1916. The eruption lasted several days, and the inhabitants were obliged to leave the island in vessels sent from Messina.

Caltanissetta, Sicily, July 6, 1916.—A violent earthquake at Caltanissetta on the island of Sicily caused three of the sulphur mines near there to cave in, and three hundred miners are said to have lost their lives.

Fiume, Austria, July 18, 1916.—Dispatches from Amsterdam report great damage done by an earthquake in the region about Fiume, Austria, at the northern end of the Adriatic sea. A panic is reported in the city of Fiume, but no details are given of the day or hour.

Bay Cities of California, August 6, 1916.—A light shock was felt in the cities about the Bay of San Francisco at 11:40+ a.m., on August 6, 1916. Mr. Leonard L. Hohl reported the shock at Sausalito, and it was felt at San Mateo, Redwood City and Stanford University. Windows rattled, and the timbers of wooden buildings creaked. The perceptible rocking movement lasted about four seconds, and the intensity was III of the Rossi-Forel scale.

Palo Alto, Cal., August 8, 1916.—A shock having an intensity of III of the Rossi-Forel scale was felt August 8, 1916, at 8:50 a.m., at Palo Alto and Stanford University. The perceptible movement lasted about four seconds.

Winnemucca, Nevada, August 15, 1916.—At Winnemucca, Nevada, a severe shock was felt at 5:15 a.m., August 15, 1916. It is said to have been the most severe felt in that part of the state for many years. No damage has been reported, but things were thrown from shelves and much alarm was felt.

Rimini, Italy, August 16, 1916.—The Associated Press reports a severe earthquake on the Adriatic coast of Italy on the morning of August 16, 1916. It was especially severe at Rimini, Pesaro, and Ancona. Houses were wrecked at Rimini and Pesaro, and at the former place four persons were killed and thirty were injured.

The members of the Seismological Society are offered an opportunity to become members of the American Association for the Advancement of Science through the Pacific Division by paying the annual dues of $3.00. Printed announcements have already been mailed to members of this Society. The older and larger scientific body thus relinquishes the initiation fee in favor of members of the smaller division, comprising besides its own members thirteen affiliated scientific bodies domiciled on the Pacific Coast. The proposed extension seems to be in the right direction, and preserves the individual and special interests, while allowing the larger contact and more diversified view of science and man's progress.

REVIEWS

SEISMOLOGICAL TABLES. By Dr. Otto Klotz. Publications of the Dominion Astronomical Observatory, Vol. III, No. 2.

Dr. Klotz has done a service of inestimable value to American seismologists in publishing a handbook of tables for the complete interpretation of seismograms in accordance with the most recent determinations of the velocity of seismic vibrations. Before the publication of this set of tables, those in charge of seismographs who were fortunate might have had for use the table worked out by Dr. Zeissig for distances from the times of *P* and *S* up to 13,000 kms.; but for determining the time at origin no satisfactory tables were available. Dr. Klotz's tables include the valuable data elaborated by Dr. Mohorovic y Agram in Hungary, the most accurately determined constants for transmission of *P* and *S* from the epicenter up to the determinable distance of 13,000 kms. Unfortunately, satisfactory data are wanting to assuredly determine distances above 13,000 kms.

The tables employ Wiechert's admirable symbols, which have now everywhere replaced, by international agreement and tacit consent, the earlier systems invented by Milne, Laska, and others.

In addition to the speed constants above referred to, the tables include data for correctly determining the amplitude of maximum motion among the *L* waves of a seismogram when the instrument has been properly damped. It is useless to publish the amplitude of undamped records, as is still a common practice. Lastly, among other useful aids to station work, the tables give the constants for locating an epicenter from a large number of North American and foreign stations according to the graphic method devised by Dr. Klotz.

With these tables in his possession even the amateur in charge of a seismograph can make accurate contributions to our knowledge of a well-recorded earthquake, provided his clock is correct to a second and he knows how to identify the phases of an earthquake recorded by a seismogram.

J. B. W.

SEISMOLOGICAL REPORTS RECEIVED.

AMERICA

Cleveland, Ohio.—St. Ignatius College Observatory, Seismological Bulletin, April 11, 1914 to March 12, 1916.

Denver, Colorado, Jesuit Seismological Service.—Sacred Heart College. Reports nos. 2 to 6, from February 1 to June 30, 1916.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, nos. 528-557, from March 1 to May 31, 1916.

Ottawa, Canada, Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 6-13, from March 1 to June 30, 1916.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 12-15 bis, from March 1 to June 30, 1916. From the same station, compiled press dispatches during the same period.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 1-12, from January 1 to June 21, 1916.

Osaka, Japan.—Seismological Bulletin of the Meteorological Observatory, from January 1 to May 3, 1916.

EUROPE

Barcelona, Spain.—Estacion Sismica de la Real Academia de Ciencias y Artes.—Reports nos. 22-25A, from January 1 to April 30, 1916.

Cartuja, Granada, Spain.—Boletin Mensual de la Estacion Sismologica, nos. 12, 1915, 1-2 from December 1915 to February 1916.

Coimbra, Portugal.—Boletim Sismico do Observatorio da Universidade, from December 1, 1915, to April 30, 1916.

Stonyhurst College, England.—Earthquake Records of the Observatory, from July 1915 to March 30, 1916.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 27-34; 1-4; from October 1, 1915, to January 31, 1916.

PUBLICATIONS RECEIVED

G. Agamennone.—Sul recente libro del Cap. G. Costanzi "Brandisismi e Terremoto." Exta. dal *Bolletino della Società Sismologica Italiana,* **18,** fas. 6, 1914.

Galdino Negri.—Determinacion de la profundidad de la costra terrestre. Extr. *Revista del Centro Estudiantes de Ingenieria.* Año XVI, no. 161. Buenos Aires, 1915.

Galdino Negri.—Qualche confronto frai valori di elementi sismici. Estratto dalle Memorie della Classe di Scienze della R. Accademia degli Zelanti 3 ser., **8,** 105-240, 1912-1915.

Bollettino della Società Sismologica Italiana, **17,** 7-12. Roma, 1914. (This volume of 646 pages consists of notes on earthquakes observed in Italy during the year 1910, compiled by Dr. G. Martinelli.)

Same, **19,** 1-2, 3-4; Modena, 1915.

Parergones del Instituto Geologico de Mexico, **5,** 1-3, Catalogos de los movimientos registrados durante el año de 1911 en las estaciones seismologicas de Merida, Yucatan, pp. 5-19; Mazatlan, Sinaloa, pp. 21-37; y Oaxaca, pp. 39-59.

Catalogo de los macroseismos sentidos en la Republica Mexicana durante el año de 1911, pp. 61-79. Mexico, 1913.

Tomo V, 6-8. Catalogo de los seismos registrados durante el año de 1912. Mexico, 1914.

Bulletin Semestriel de l'Observatoire Météorologique de Séminaire—College St. Martial, Port-au-Prince, Haiti, Jan.-Juin, 1915.

Count Montessus de Ballore.—*Boletin del Servicio Sismologico de Chile,* **10.** First semester of 1913. Santiago, 1915.

Same **11,** Memorias. Santiago, 1915.

Count Montessus de Ballore.—Historia Sismica le los Andes Meridionales al sur del Paralelo XVI, Quinta parte. El Terremoto del 16 de Agosto de 1906. Santiago-Valparaiso, 1915.

Count Montessus de Ballore.—Bibliografia General de Temblores y Terremotos. Tercera Parte: Paises curcunmediterraneos, pp. 257-502. Publicada por la Sociedad Chilena de Historia y Geografia. Santiago de Chile, 1915.

Quarta Parte: Asia, Africa y Ociania, pp. 505-613. Santiago de Chile, 1916.

Count Montessus de Ballore.—Las voces del Coloso de Memnon ante la sismologia. Extr. de la *Revista Chilena de Historia y Geografia,* **18,** 32. Santiago, 1916.

Count Montessus de Ballore.—L'oeuvre sismologique de J. Milne. Extr. *Revue des Questions Scientifiques,* avril 1914, 8°, pp. 5-38. Louvain, 1914.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

MAY 17, 1916.

In the absence of the President the meeting was called to order by Vice-President Tolman, at 3 p.m., in Room 66, Stanford University, Cal. Directors Branner, Durand, Taff, Tolman and Townley were present.

The minutes of the meeting of the Board of Directors on February 16, 1916, were read and approved.

The report of the Board of Election was read by the Secretary.

After being duly nominated, the following officers were elected for the year:

President	J. B. Woodworth
First Vice-President	C. F. Tolman, Jr.
Second Vice-President	Ralph Arnold
Third Vice-President	C. F. Marvin
Secretary-Treasurer	S. D. Townley

The report of the Secretary-Treasurer for the year ending April 1, 1916, was read and ordered filed.

The report of the Auditing Committee was read by Director Durand and ordered filed.

By motions duly made and seconded the following named persons were elected to membership in the Society: C. C. Chu, Cambridge, Mass.; Maxwell Hall, Montego Bay, Jamaica; A. M. Jung, Spokane, Wash.; Ivan R. Ralston, Calexico, Cal.; Frederick Paul Vickery, New York, N. Y.

After considerable discussion, it was decided to reduce the number of copies printed of the Bulletin from 1000 to 700.

The salary of the Secretary-Treasurer was continued for one year at the rate of $20 per month.

Adjourned at 4:15.

S. D. Townley, *Secretary.*

REPORT OF THE BOARD OF ELECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA

San Francisco, Cal., April 1, 1916.

PRESIDENT AND MEMBERS OF THE SEISMOLOGICAL SOCIETY:

We, the undersigned judges of election, certify that 123 ballots were cast at the annual election, held in San Francisco on this date, with the following result:

Ralph Arnold	97	H. F. Reid	109
J. C. Branner	120	R. W. Sayles	37
E. F. Davis	31	W. D. Smith	39
F. N. Denison	22	J. A. Taff	82
W. F. Durand	87	C. F. Tolman, Jr.	104
W. H. Hobbs	52	S. D. Townley	111
Otto Klotz	38	Otto von Geldern	60
A. C. Lawson	114	H. O. Wood	44
A. G. McAdie	94	J. B. Woodworth	92
C. F. Marvin	100		

The following named, being the twelve receiving the highest number of votes, are declared elected directors of the Society for the year 1916-17.

J. C. Branner
A. C. Lawson
S. D. Townley
H. F. Reid
C. F. Tolman, Jr.
C. F. Marvin

Ralph Arnold
A. G. McAdie
J. B. Woodworth
W. F. Durand
J. A. Taff
Otto von Geldern

D. S. RICHARDSON, *Chairman*,
R. L. ROWLEY,
B. A. BAIRD,
Board of Election.

REPORT OF SECRETARY-TREASURER.

From April 3, 1915, to April 1, 1916.

The total number of members of the Society and subscribers to the Bulletin is now 410, a decrease of 4 during the year.

One of the most interesting earthquakes of the year occurred on June 22d in the Imperial Valley, California. The Society is indebted to Dr. J. C. Branner for a generous gift of $402.95 to pay the expense of investigating this earthquake, and for the illustrations of Mr. Beal's article.

Volume 5 of the Bulletin, containing 263 pages and 26 plates, was issued during 1915.

The financial report is as follows:

General Fund

Dr.

To balance, April 3, 1915	$ 83.93
Dues and subscriptions	702.98
Reprints	25.70
Sale of publications	37.50
Drawings	4.00
Gift from J. C. Branner	402.95
Transfer from Sayles Fund, interest	258.45
Transfer from Sayles Fund, principal	300.00
Transfer from Life Membership Fund, interest	17.45
Total	$1,832.96

Cr.

By Stanford University Press, printing Vol. 5	$ 841.95
Stanford University Press, reprints	82.14
Stanford University Press, miscellaneous printing	17.47
Commercial Art Co., illustrations	36.56
Sunset Publishing House, illustrations	100.40
C. H. Beal, investigations of Imperial Valley Earthquake	363.30
Drawings	5.60
Second-class postage on Bulletins	7.73
Foreign postage on Bulletins	10.50
Miscellaneous postage	14.00
Rent of safe-deposit box	2.00
Salary of Secretary-Treasurer	240.00
Balance, April 1, 1916	111.31
Total	$1,832.96

Dr. LIFE MEMBERSHIP FUND

To balance, April 3, 1915	$ 425.00
One life membership (Veatch)	25.00
Interest from Berkeley Bank of Savings and Trust Co.	17.45
Total	$ 467.45

Cr.

By interest, transferred to General Fund	$ 17.45
Balance, April 1, 1916	450.00
Total	$ 467.45

Dr. SAYLES FUND

To Balance, April 3, 1915	$4,475.00
Interest from Mutual Building and Loan Association of San Jose and College Park	60.00
Interest from Palo Alto Mutual Building and Loan Association	120.00
Interest from Truckee Lumber Co.	60.00
Interest from Bank of Palo Alto, Savings Department	18.45
Total	$4,733.45

Cr.

By transfer to General Fund, interest	$ 258.45
Transfer to General Fund, principal	300.00
Balance, April 1, 1916	4,175.00
Total	$4,733.45

S. D. TOWNLEY,
Secretary-Treasurer.

AUDIT OF THE SEISMOLOGICAL SOCIETY OF AMERICA.

April 3, 1915, to April 1, 1916, inc.

GENERAL FUND

Balance April 1, 1916 .... $ 111.31

Properly receipted vouchers submitted for each credit and dues correctly debited to this amount. The amount is on deposit at the Bank of Palo Alto in a regular commercial account.

LIFE MEMBERSHIP FUND

Balance April 1, 1916 .... $ 450.00

This amount is on deposit in the Berkeley Bank of Savings. It represents $425.00 on hand at beginning of fiscal year, plus interest and one new Life Membership.

SAYLES FUND

Condition as follows, April 1, 1916:

Balance in Palo Alto Savings Bank	$ 175.00
Certificate No. 158, Palo Alto Building and Loan Association	1,000.00
Certificate No. 159, Palo Alto Building and Loan Association	1,000.00
Certificate, Mutual Building and Loan Association	1,000.00
(These certificates all bear interest at the rate of 6%, and interest on that basis has been properly debited to the account.)	
Truckee Lumber Co., first mortgage, 6%, Gold Bond	1,000.00
Interest collected and properly entered	
	$4,175.00

General Fund	$ 111.31
Life Membership Fund	450.00
Sayles Fund	4,175.00
	$4,736.31

Respectfully submitted,

J. K. MOFFITT,
W. F. DURAND,
OTTO VON GELDERN,
Auditing Committee.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

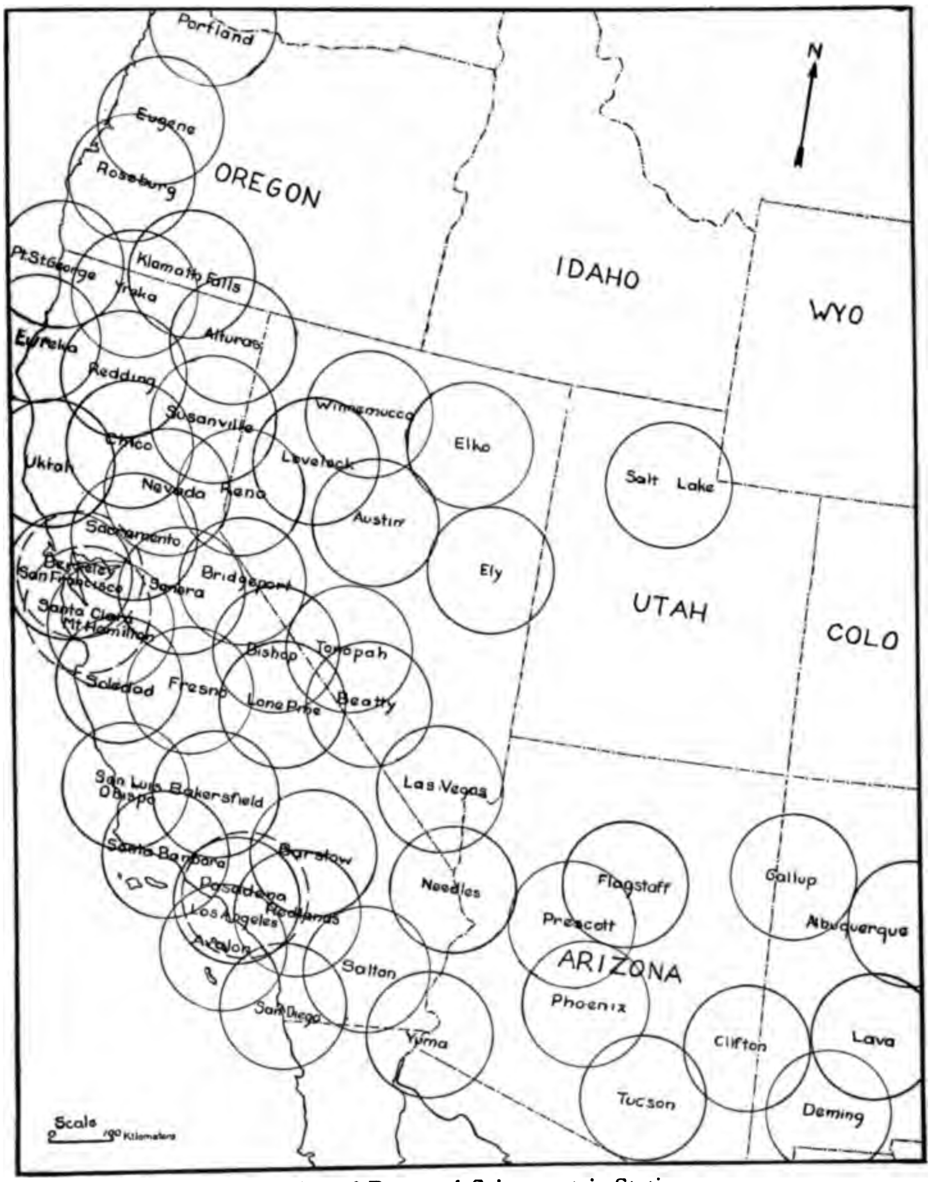
VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.



Location of Proposed Seismometric Stations

The Bulletin of the
Seismological Society of America

VOL. VI DECEMBER 1916 No. 4

THE EARTHQUAKE PROBLEM IN THE WESTERN UNITED STATES

By Harry O. Wood

In the western and southwestern part of the United States are extensive areas where earthquakes happen frequently. Together these make up nearly all of a great region which, at the very least, includes southwestern Oregon, California, western Nevada, and large parts of Arizona and New Mexico. The true limits of this seismic province (within the boundaries of the United States) probably would embrace a much larger territory still. And the province undoubtedly extends far to the south within the domain of Mexico.

Both strong earthquakes and weak occur here. At irregular intervals, the longest of which has been a few decades only, one locality after another has been the theatre of action of a shock of great energy—abundantly strong to be destructive. However, throughout the short span of time over which we have any history of this region, these major shocks, in nearly all instances, have originated beneath districts where previously no strong shocks had been generated for a very long time. Also, the tracts in which destructive intensity has been developed have rarely been large in area, and in most cases these have been situated wholly or in part in mountainous country. In consequence of these conditions the destructive action of these great shocks has been minimized, and scattered geographically, so that—should they continue to occur in this way—the menace from them is not so general nor, on the average, that for a particular place, so great as is commonly supposed by many who dwell in lands where earthquakes are rare and always feeble. Even in districts visited by high intensity *well-made structures of suitable design* usually have sustained no great injury. On the whole it appears reasonably certain that in this Pacific seismic province earthquakes threaten life less and property no more than do tornadoes, blizzards, electrical storms and floods in other parts of the country; while these hazards of climate are absent, or nearly so, from this western region.

Nevertheless, three or four important communities in California alone have been shaken severely by major earthquakes on several occasions in the past century. These shocks emanated from different focal localities. Thus these communities, and certain others, are menaced by earthquakes from more than one direction or source. Consequently the fact that any of these has suffered once in recent years does not give it promise of immunity in future. For there is overwhelming geologic evidence that here great earthquakes have originated again and again in localities which overlap each other along recognizable belts—"living" zones of geological faulting; and that in the course of recent geologic time great numbers of powerful earthquakes have originated all along these faults, produced by deep-seated fracture and slipping in the rock crust. It is equally sure that such shocks will continue to occur sporadically in this province, just as storm centers will surely form and sweep destructively through other regions.

Moreover, the advent of a strong earthquake is sudden, a considerable district is stricken simultaneously, with impairment or paralysis of means of communication and transport, disastrous fires often ensue, and there is no public warning whatever,—usually no prelude is noticed which is clearly intelligible, even to students of these phenomena. Consequently a degree of surprise, and of panic, is associated with earthquakes beyond that occasioned by other natural disasters. Besides, on rare occasions, the intensity in small districts has risen so high as to imperil all but the best structures,—sometimes even these.

Therefore it must be clearly recognized that throughout this large seismic province the occurrence of strong earthquakes is *in moderate degree* a menace to life and property,—in a degree greater than many residents of the region are willing to admit. It is idle to deny this, or to strive to conceal it. In justice to the future development of this great, important region, care must be exercised not to overemphasize this danger, which, *as already stated,* is not great, nor, in a given locality, always threatening. But the fact of the existence of this danger must receive emphasis, for there are many who strive to belittle it. Ultimately, without question, the attitude of these will prove more injurious to the welfare of the region. Indeed, tacitly, a bad public policy has been instituted in parts of California,—in consequence of which the present writer is induced to quote at some length from an excellent article by Gilbert,[1] the entire body of which is germane to the matter in hand.

> As long ago as 1868, Whitney, speaking of the Pacific States, said:
>
> "The prevailing tone in that region, at present, is that of assumed indifference to the dangers of earthquake calamities . . . the author of a voluminous work on California, recently published in San Francisco, even going so far as to speak of earthquakes as 'harmless disturbances.' But earthquakes are not to be bluffed off. They will come, and will do a great deal of damage. The question is, How far can science mitigate the attendant evils, and thus do something toward giving that feeling of security which is necessary for the full development of that part of the country?"
>
> This policy of assumed indifference, which is probably not shared by any other earthquake district in the world, has continued to the present time, and is accompanied by a policy of concealment. It is feared that if the ground of California has a reputation for instability, the flow of immigration will be checked, capital will go elsewhere, and business activity will be impaired. Under the influence of this fear, a scientific report on the earthquake of 1868 was suppressed. When the organization of the Seismological Society was under consideration, there were business men who discouraged the idea because it would give undesirable publicity to the subject of earthquakes. Pains are taken to speak of the disaster of 1906 as a conflagration, and so far as possible the fact is ignored that the conflagration was caused, and its extinguishment prevented, by injuries due to the earthquake.

This policy prevails today, with even greater effectiveness than when Gilbert wrote: by repeated iteration it has gained momentum. It is in marked contrast to that adopted in Japan, Italy, Chile and Mexico; and it reflects grave discredit upon the intelligence of this western American community, even though we recognize that it is a matter of motive. Especially is it a strange attitude to encounter in a community of men whose chief distinction has been a ready and efficient dealing with natural difficulties.

Gilbert continues:

> The policy of concealment is vain because it does not conceal. It reflects a standard of commercial morality which is being rapidly superseded, for the successful salesman of today is he who represents his goods fairly and frankly. It is unprofitable because it interferes with measures of protection against a danger which is real and important.

So much attention is given here to this public, or quasi-public, attitude, because, in the judgment of the writer, the danger arising from the prevalence of it is far greater morally, financially, and in menace to human life, than the danger from the physical shock of earthquake frankly faced and prepared for.

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[1] Gilbert, G. K.: Earthquake Forecasts. *Science*, January 22, 1909.

In point of fact, California, and other large parts of the west and southwest, are confronted with a group of earthquake problems which in fundamental nature are geological and physical,—but the solution of them is of paramount human and economic importance.

These are:

Where, and when, in this province will earthquakes of great power originate;
Under what conditions, and in what ways, does their energy operate to produce disaster; and
What practical measures can be devised *and enforced* to minimize danger from their occurrence, and to mitigate disaster when destructive shocks come?

Can these problems be solved—and at practicable cost?

In reply to this: We already have knowledge, though fragmentary and disconnected, with regard to conditions which have proved especially dangerous, and so in a small way in regard to protective measures. Also, we know some of the localities in which future strong shocks must originate; others we can point to with much assurance of future action; and many others, doubtless, we know nothing of as yet. At what future times shocks will occur we do not know, especially in any precise way; but we do know that since 1769 no half-century has passed without the occurrence of at least one great earthquake in this region. The average points conclusively to greater expectable frequency. However, close prediction of occurrence as of day or hour, even of month or year, cannot even be approximated as yet. Before this can be hoped for, a large body of experience with delicate registering mechanisms must be gained.

Up to the present day there has been no systematic or sustained study of earthquakes in this province, nor in the United States,—though in very recent years a considerable number of stations, located accidentally, have been equipped with registering seismographs.

In Italy and in Japan systematic studies have been in progress under authorized scientific commissions for a considerable number of years. Italy, surely, stands in no greater natural danger from earthquakes than does this American province—though the buildings in its cities may be somewhat less resistant than in ours. Japan experiences a greater number of shocks, but it is doubtful if powerful shocks visit it more frequently. In recent years, as the result of the occurrence of disastrous shocks, systematic seismological work has been undertaken in Chile and in Mexico, under the auspices of those governments. But no move has yet been made in the Pacific Region of the United States, although six, or seven, strong earthquakes have visited this province since 1857.

If we look to their importance to human life alone the problems raised by earthquake occurrence in this region demand systematic and sustained investigation in the open field, in seismological laboratories, and in engineering science. For their coming will not continue to find the land scantily peopled, nor will they always choose for their visit hours when the populace is at home and asleep, or in other ways scattered. Sound building practice, and sound, enforceable legislation in regard to building and building-sites, for the protection of the public, must depend primarily upon knowledge gained by such work. And such a body of experience and of concrete facts, IF HEEDED, will save in money in a short term of years many, many times its money cost. Obviously it cannot be HEEDED before the knowledge is acquired.

Moreover, such systematic investigations inevitably will increase immensely our knowledge of the physics of the earth, and of the specific, dynamical behavior of the earth's crust in this province,—ends sufficient in themselves to justify the establishment and maintenance at public expense of a large scientific enterprise; and this undertaking is now much more important than the erection of additional astronomical observatories, or the reduplicating of the plants of other well established branches of science. Whitney long ago pointed out the importance of investigations in earth physics in this region. At this day one would think it unnecessary to point out the value—even commercial value—the work of such an enterprise may come to have.

In Europe, although comparatively little of its area has ever been visited by really powerful earthquakes in the whole course of written history, a number of special institutes for geophysical investigation (to say nothing of numerous seismological stations of the routine sort, and better) have already been established under government support, because there the importance of the study of fundamental natural problems is clearly recognized in an enlightened public policy.

To view the trend of seismological study let us consider the expressed judgment of Charles Davison, one of the foremost students of earthquakes in England, who has written:

> After an experience of nearly twenty years I have no hestitation in saying . . . that the careful investigation of earthquakes may point to the existence of deep-seated faults, beyond the scope of the geologist, and will in time lead to the discovery of the laws according to which faults grow.

The discovery of such laws makes a long step toward the precise prediction of the happening of earthquakes; so that knowledge of their operation cannot fail to have great practical importance in regions of growing mountains, or in all provinces of high seismicity. It follows clearly that seismological study, broadly interpreted, is of vital importance in the west and southwest region of the United States; that here there is a great opportunity—and a great need— for the founding of an Institute of Seismology and Geophysics.

It is desirable, therefore, to outline the work such an Institute should undertake.

In seismic lands thickly populated by civilized people, as this Pacific Coast province now is and will grow more and more to be, the necessary scientific and practical study of earthquake phenomena must proceed naturally along three distinct lines of endeavor, namely: (1) geophysical field studies, comprising specially directed geologic and geodetic inquiries, gravity surveys, magnetic surveys, and so on; (2) geophysical laboratory studies, comprising routine seismometric registration conducted under practically uniform conditions at a sufficient number of stations; seismologic research, precise physical investigations, instrumental experimentation, and geological experimentation; and (3) practical engineering investigations in regard to the destructive action of powerful earthquakes.

To a certain extent the lines of these studies interweave, and their domains overlap. But especially do (1) geophysical field study and (2) geophysical laboratory study, as here indicated, support and stimulate each other, standing apart somewhat from (3) the engineering studies.

For *the engineering inquiries* can be conducted on sound lines by none except practical engineers qualified by thorough training and large experience. Further, while shop tests of experimental character may need to be made occasionally, and though slight revisions in theoretical procedure conceivably may be called for to adapt engineering practice to the conditions which are brought about by strong earthquakes, very little progress can be made in solving the problems of this category except by direct study of the results produced in structures by great shocks. Consequently when earthquakes occur strong enough to produce significant damage in important works of construction, leading engineers, in pursuit of knowledge vital to their profession, will take large advantage of the opportunities thus afforded to find principles and practices in construction better adapted to withstand the unusual strains generated by strong seismic motion. At ordinary times these men will be occupied continually in professional work; so that, but for these rare instances, they will find little opportunity for such scientific investigations. Moreover, in their practice are involved not merely scientific qualifications, but, even more, business acumen and the practical application of economic principles to work. They are often governed by situations not resolvable in strict accord with ideal, scientific procedure. Therefore, though competent engineers may learn much of profit in this connection from the work of geophysicists in field and laboratory, this domain, of seismic engineering studies, is peculiarly their own; and, obviously, does not constitute a part of the field proper to an Institute of Seismology and Geophysics, though special investigations might well be undertaken by such an institution in collaboration with engineers.

On the other hand, the field study of earthquake phenomena and their investigation by laboratory methods both necessarily are conducted along strictly scientific lines (as distinguished from methods of business), and are allied closely in aim and method, thus reinforcing each other so strongly that they may be administered with great advantage under one and the same institution.

I. STUDIES IN THE FIELD

This division of the work is of great *practical* importance in the Pacific Coast region.

Geologic Studies

First there should be a thorough *search for living faults*: a specialized survey of the surface geology, to extend our knowledge of the location and critical characteristics of the zones of outcrop of these rock-fracture systems where still, at intervals, slipping occurs, producing relative displacements of great crust-blocks on opposite sides of the fault. For such slipping within these fault fracture-systems is the immediate origin of all, or nearly all, the earthquakes experienced in this region.

Such geological study would not encroach upon the ordinary work of a geological survey, because of its special and intensive character and its restricted method of work.

Briefly: in this region some faults which we know already to be *living*, intersect the rock and soil surface along narrow, linear zones; in some ways valley-like, yet unlike any river or glacier valleys, or ordinary diastrophic valleys,—merely degraded, weak zones of "broken country," susceptible of rapid attack by erosion. In these are found small knolls, small pools, rush-ponds, marshes, small embankments and escarpments, all of these irregularly formed and delimited and irregularly distributed within and along these narrow, linear belts, above the broken and dislocated crust-blocks, which mark the outcrops of the faults. The experienced eye recognizes these features easily. Therefore what is needed at first is the finding and mapping of all such weak zones, for there is little doubt that in all cases they mark the course of *living* faults. Already some slight progress has been made in such search.

Other zones, marked by somewhat different characteristics, will doubtless come to light.

After work of this kind is successfully under way, in some districts detailed studies will be found necessary to learn the complex mechanisms, structure-relationships, and dynamical behavior of some of these faults which exhibit clear evidence of historical, or geologically recent, dislocation. This work also would be strictly geological, but of a very special nature.

Geodetic Work

The fault slip in California in 1906 was so great in amount that it was deemed necessary for the U. S. Coast and Geodetic Survey to re-survey much of their systematic triangulation in the central part of the state. In earlier years, beginning in 1851, this system of triangles had been surveyed in a piecemeal way more than once. No work was done on this system between 1866 and 1874, an interval during which the destructive shock of 1868 occurred, nor between 1892 and July 1906, near the end of which interval came the 1906 shock. The re-survey begun in 1906 was completed in 1907. Careful reduction of these surveys brought out the fact that a definitely recognizable distortion of the region of Central California had come about during the interval 1866-74, in which the 1868 shock occurred; and again during the interval 1892-1907, in which the 1906 shock happened. Professor H. F. Reid has shown reason for thinking that these distortions are produced in part progressively over the whole region, and in part suddenly at the time of the shock as violent flings producing great distortion in the immediate neighborhood of the fault trace.

In view of these phenomena, since the primary triangles of this system are the basis of all accurate surveys of this region, and since the *early discovery of progressive distortion in any district* is of prime importance from the economic and human point of view, as well as a scientific datum of invaluable character, *geodetic surveys of sufficient scope to check the whole system* should be undertaken at intervals of only a few years. Such work could best be carried on by the U. S. Coast and Geodetic Survey, but the motive for its frequent repetition would be the detection of critical crust strain; and circumstances might necessitate the active coöperation of the geophysical enterprise, or even an independent undertaking.

As a result of the findings in 1906-07, provision has already been made at two places, on the line of the San Andreas Fault, for the frequent survey of systems of monuments in order to detect any slow local, progressive distortions. As yet these monument systems are confined to *the immediate zone of this single fault,* and both sets of stations are in a region recently relieved from excessive strain.

Frequent survey of fixed monuments in larger systems, at an adequate number of stations located with reference to recognized faults, would not only be of great scientific interest, but probably would detect very definitely places of rapidly growing strain, and thus contribute very valuable data for prediction,—a practical point of great importance.

This would be refined geodetic field investigation which would follow, necessarily, the detection of living faults, whether by geological study, the work of seismometric registration, or by the occurrence of disastrous shocks. Such work would be undertaken by the Institute as part of its proper routine, or in collaboration with the Coast and Geodetic Survey. As this latter Bureau is now organized it could not regularly undertake such a routine independently.

Miscellaneous Field Studies

Magnetic and Gravity Surveys: Experiments.— It has been found that the distribution of earth magnetism sometimes is affected markedly when strong earthquakes occur; also that such shocks often occur in regions characterized by relatively rapid variations in the value of the constant of gravity from one locality to another.

Consequently much scientific interest, and possibly practical value, attaches to the study of earth magnetism and its distribution, and of gravitational potential as well, throughout regions of known seismic activity. In connection with the latter subject may be mentioned the gravimeter due to Baron Eotvös, a device brought to the attention of seismologists not long ago by Prince Galitzin, who referred to it as "an instrument of the highest sensitiveness, which enables us to detect the presence or displacement of comparatively very small masses."

Such investigations can hardly fail to bring very important results. Except that these studies should be undertaken in relation to faults, they depend less intimately upon geological studies in the field, and do not need to await the prosecution of these.

Microphonic Investigations.—Along the course of one of the living faults the following experimental investigation should be undertaken, since it may pave the way toward definite prediction. If successful, such a method should form part of the routine along every recognized living fault.

To digress briefly: when in the laboratory testing of wood, metal, stone, etc., the substance is stretched, compressed, bent or twisted beyond its elastic limit, it suffers permanent distortion; and then if the distorting force continues to be applied the substance *fails* more and more rapidly, ending with fracture. During the progress of *failure* the minute disruptive displacement of the particles sets up suddenly groups of vibration of great rapidity and exceedingly small amplitude, which grow in energy and frequency of occurrence as fracture is approached. Usually these can be heard as cracking sounds or "cries."

It seems sure that, prior to and during the fracturing which must precede and make possible the fresh slipping of crust-blocks along a great fault, there must be a similar period of progressive failure, with the emanation of more and more groups of vibrations of increasing energy. Now the microphone not only renders audible sounds of the feeblest character, but also it is a device very sensitive indeed to minute vibrations of purely mechanical character, which in the microphone become transformed into sounds—a transformation which greatly magnifies them. Therefore it is probable that if delicate microphones specially designed and adapted for the purpose should be sunk in deep-bore holes along the course of living faults and there embedded in rigid connection with the deep rock (in order to isolate them from all surface vibratory movements), these, by their excessively sensitive registration of minute and feeble vibrations, would indicate the approach of failure and fracture long in advance. To be sure, a great deal of data of this kind would have to be gathered and digested before a clear understanding of its meaning could be gained. The details of mechanism and of registration present difficulties, but these do not appear to be insurmountable.

A number of years ago De Rossi, in caves by the seashore in Italy, experimented with crude microphones and obtained interesting results. It is not impossible that an investigation of this kind, worked out thoroughly, may afford a basis for refined prediction; but of course there can be no definite promise of this.

The study which utilizes microphones, and the magnetic and gravity investigations, while in a real sense work *in the field,* perhaps might be considered more properly among investigations in the laboratory. At any rate these connect intimately the field and laboratory branches of the undertaking, and make direct coöperation a practical necessity.

II. STUDIES IN THE LABORATORY

Routine Seismometric Work and its Synthesis

By far the most definite, practical and important of the methods of earthquake study in the laboratory is routine seismometric registration, if it is conducted with *adequate* instruments suitably installed at a *sufficient number of stations.* In the province under consideration this work is of even greater importance than the geological search for *living* faults,—and it will aid and direct geologists in finding them.

In the past decade or so the development of the seismometer has gone forward very rapidly. Now, from the records made by the best types, we obtain a fairly precise measure of the character, amount, direction and tempo of the earth vibrations, the rates of propagation of the principal types of waves, the angles of emergence of the wave-trains, and, usually, we can determine the distance and direction of the focal region and so its geographical location, and the depth of the origin—especially when the data of several stations are available for a given shock.

Locating the place of origin thus precisely is of great practical value, particularly in the case of weak earthquakes. For in this province weak shocks indubitably emanate from living fault zones; and, except when they are after-shocks of a strong or violent earthquake, they point to a growing strain approaching a condition which must be relieved by fracture and faulting sooner or later. Therefore, by locating definitely the origins of all the weak shocks that occur, and observing where these tend to cluster and the frequence of their occurrence, we may deduce with much confidence the *places* where strong shocks are to originate, considerably in advance of their advent. For, usually, numerous minor fractures and slippings, producing weak shocks, should precede the major failure. If not invariable, this would be true frequently. Thus, with accumulating experience, *generalized prediction* of place, and less confidently of time, should become possible.

It should be clear, therefore, that it is very desirable, not to say necessary, to detect and register all the weak shocks of this region. To accomplish this a considerable number of seismographic stations must be established and maintained.

Up to the present no seismometers of the most highly developed type have been employed in this western region.

However, on the occasion of the earthquake in Central California on July 1, 1911, at Berkeley there were recording two components, Bosch-Omori 100-kilogram tromometers, and a Wiechert 80-kilogram Vertical Seismograph; at Mt. Hamilton, and also at Santa Clara, a precisely similar vertical seismograph and a two-component Wiechert Astatic Pendulum Seismograph of about 80-kg. mass, were at work. The focal region of this shock, and its after-shocks, lay some 16-32 kilometers (10-20 miles) southeast of Mt. Hamilton, and some 90-130 kilometers (55-80 miles) southeast of Berkeley.

A considerable number of very feeble after-shocks which were registered at Mt. Hamilton were not registered at all at Berkeley, and quite a number of these were not registered at Santa Clara, distant from 30-60 kilometers (19-38) miles. In a few cases, shocks plainly registered at Mt. Hamilton were registered illegibly at Berkeley. This was due to decay of energy, and not to instrumental insensitiveness; for during these weeks several feeble teleseisms were registered at Berkeley, but not at the other stations.

More recently, working at Kilauea, with Bosch-Omori 100-kilogram tromometers, two components, it has been found by the writer that of 441 shocks registered determinably in a little less than two and a half years, more than 96% originated at a distance less than 50 kilometers, and about 87% at a distance less than 40 kilometers. Of the 3.6% which came from distances greater than 50 kilometers, several were generated at considerable near-distances up to 500 kilometers, and were deeper and more energetic earthquakes than most of the weak shocks. In certain cases it is known definitely, and in many more it is suspected strongly, that moderate weak shocks *felt* very perceptibly at places distant no farther from Kilauea than 70 kilometers were not registered at the Kilauea station. There are sundry excellent reasons for thinking that many weak shocks on Hawaii, originating at distances greater than 50 kilometers, have failed to be registered here because of decay of energy.

Therefore it appears that with excellent instruments (not of the types most sensitive of all) very weak shocks, which should be telling harbingers of strong ones, cannot be registered with certainty or satisfaction at distances greater than 100 kilometers from their origins; and it is doubtful if a majority of them can be registered well at distances greater than 50 kilometers. With the best types available these limits may be extended a little; so that a radius of 100 kilometers (60 miles) may be taken as a satisfactory working radius.[2]

Hence, in order to fix the location of all weak shocks, seismometer stations must be distributed so that no localities where shocks appear likely to originate shall be at greater distance from a station than this working radius. Some progress, certainly, can be made by working with fewer stations; but the entire region cannot be studied adequately without such a network,—until much more sensitive seismometers become available.

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[2] Furthermore, Walker* states: "I was never able at Eskdalemuir to detect any indication of earthquakes reported to have taken place in Perthshire, and even the Glasgow earthquake of December 1910, which caused considerable public excitement there, produced no perceptible effect on the Eskdalemuir seismographs."

Eskdalemuir is a station of the first class, equipped with a "Milne * twin-boom seismograph, a Wiechert 80 kgm. two horizontal components astatic inverted pendulum seismograph, a complete Galitzin installation of seismographs with galvanometric registration for three components, and an Omori seismograph for one horizontal component." The Milne type and the Galitzin type seismometers are the most sensitive yet devised (excepting possibly the 17,000 kgm. pendulum of Wiechert at Göttingen).

Glasgow is slightly less than 100 kilometers distant from Eskdalemuir. All of Perthshire lies at greater distance. Hence the findings in California, and in Hawaii, are sustained and emphasized by these in Scotland, which were of superior instrumental excellence.

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* Walker, G. W.: "Modern Seismology," pp. 83/84, viii. London, 1913.

SYSTEMATIC DISTRIBUTION OF SEISMOMETER STATIONS

(A) For the Whole Region

First will be outlined the geographical distribution of a system of seismometer stations necessary to an adequate network for the whole province, taking account both of the needs of the problem and the distribution of population and industry.

Places are indicated on the accompanying map, except Seattle, Elko, Ely and Salt Lake City, where stations should be established so that most localities—all important ones—shall be within 100 kilometers of at least one station, and preferably of more than one. *Minor* changes in the distribution of stations can be made in the location of stations without decreasing the efficiency of the network, if circumstances make such changes desirable.

Since work of laboratory nature, other than routine seismometry, will need to be undertaken, some of these stations will require more complete equipment and more extended facilities than others. Three classes of stations may be distinguished, as characterized and discussed below. In the following list, of places shown on the map, together with Seattle, Elko, Ely and Salt Lake City, different type-faces are employed to indicate where stations of different classes should desirably be placed.

Of these, one of the stations of the first class should be the seat of administration, and the general geophysical laboratories should be located there. Also office room, and working room, for the field workers, as well as those employed in the laboratory, should be located there.

For this whole network, or almost any large part of it, both geographically and in regard to railroad mileage, the neighborhood of Los Angeles appears to be most central, and in many ways best suited, for the location of the chief station. Also, if, as discussed and recommended below, only the smaller southern network be established at first, Los Angeles is still the most central and most suitable place.

At quite a number of places designated above among stations of the third class—either because the scientific problem of the immediate region is complex, or because the place is distant somewhat more than the preferred minimum of 100 kilometers from its neighbors—an equipment somewhat better or more extensive than that of the standard station of the third class is very desirable, though valuable

PROPOSED SYSTEMATIC LOCATION OF STATIONS

STATIONS OF FIRST CLASS
Stations of Second Class
Stations of Third Class

SEATTLE					
PORTLAND					
Eugene					
Roseburg	Klamath Falls				
Crescent City	Yreka	*Alturas*			
Eureka	Redding	*Susanville*	*Winnemucca*	*Elko*	
	Chico	Reno *Lovelock*	*Austin*	*Ely*	*Salt Lake*
Ukiah	{ Nevada City Grass Valley				
	Sacramento				
SAN FRANCISCO (BERKELEY)	Sonora	*Bridgeport*	*Tonopah*		
Mt. Hamilton (Santa Clara)		Bishop	Beatty		
	Fresno	*Lone Pine*	*Las Vegas*		
Soledad	*Bakersfield*				
San Luis Obispo					
Santa Barbara		*Barstow*	*Needles*	Prescott	Flagstaff
LOS ANGELES (PASADENA)		Redlands		Phoenix	*Clifton*
Avalon		Salton			
San Diego			*Yuma*	TUCSON	

Gallup	ALBUQUERQUE
	Lava
Deming	El Paso

work could be done with standard equipment only. These places are italicized in the list given above.

(B) For a Southern Sub-Province.

In the pages immediately preceding, an extensive network covering practically the whole province is indicated. But the immediate establishment of stations at all points of this network is *not* recommended.

In applying a science in which improvements and innovations in the apparatus of research are being introduced at frequent intervals, and one withal whose immediate practical value is in need of demonstration *to the public*, it is inadvisable to undertake the establishment of many stations at the beginning. From every point of view it is better to begin this inquiry with one station of the first class and several subordinate stations located suitably in a restricted district of this great area. Then as experience dictates, the network can be extended, either gradually or rapidly, and both the equipment and the placement of stations can be modified in accordance with accumulating knowledge.

The portion of Southern California cut off between the Mexican boundary and a line joining San Luis Obispo and Needles delimits a most suitable sub-province in which to initiate this undertaking, because, (*a*) it is a comparatively small district which can be taken care of adequately with less than a dozen stations—in which, indeed, an auspicious beginning can be made with five stations; (*b*) it is in large part a thickly settled district of much economic importance; and (*c*) it was visited by several disastrous earthquakes between 1769 and 1857, inclusive, since when it has been visited by light or moderate shocks only; whence—on the probable assumption that earth strain is still accumulating in that part of the region—not many years should elapse before the occurrence there of further strong earthquakes. For these the community within the district should be prepared.

In contrast, the region of Central California has been visited by several strong shocks more recently than 1857, three seismographic stations are at work in it, and two at least of its active faults are under scrutiny: so that it is a district less in need of investigation than that in the south. There is no other small district which appears to need inquiry so much as this.

For the initiation of work in this sub-province, stations are recommended at the places listed below. The five marked with an asterisk

(*) are considered essential; but all are highly desirable. The classes of these stations are indicated by type-faces as in the more complete list.

(*) *Santa Barbara* *Barstow* *Needles*
(*) LOS ANGELES
(PASADENA) (*) Redlands
Avalon (*) SALTON
(*) SAN DIEGO *Yuma*

The frontispiece map shows the distribution of proposed seismometric stations.

The early undertaking of this work is advocated urgently: at first on a relatively small scale, as outlined immediately above, but preferably under auspices that will allow of its extension as needed, without fresh inertia to overcome or friction to encounter. Of course no work can be undertaken until financial provision has been made for it.

SEISMOLOGIC RESEARCH

It is impossible to say exactly what trend work of this character may take, dependent as it is upon facilities, seismic happenings, and the qualities of imagination and training of those engaged in it.

In Europe the analysis of seismograms, and the correlation of this work with theoretical studies, has resulted in an extended body of knowledge of the character and mechanism of earthquake wave-motion and, thence, to rational inferences regarding the constitution and structure of the inner earth. Studies of the transmission of electro-magnetic waves also have led to inferences in regard to conditions in the depths. The specific properties of different kinds of waves have been studied, and their speeds of propagation with reference to rock material and to direction. All this is in need of much more extended study from all possible points of view.

Earthquake frequency, and seismicity—or the distribution of occurrence of shocks with reference to time and place—are fields of inquiry of much importance: for both are dependent directly on conditions prevailing around about an earthquake generatrix, usually a living fault, and (frequency particularly) they have more or less direct relationship with cycles in earth-strain which are due to various causes as yet not well understood or discriminated, such as alternations of season, the sun-spot cycle, that of variation of latitude, the numerous variations in tidal stress, and so on. In fact the measurement and correlation of earth-tides probably is more properly a function of seismology than of any of the allied branches of science, such as astronomy or geodesy, under which such investigation has been conducted hitherto. The value of these inquiries with reference to ultimate prediction, as well as to the development of fruitful theoretical studies, should need no emphasis.

Earthquake wave-shadows, interference-belts and bridges have often been alluded to: they are theoretical consequences of the passage of earthquake waves through a country of broken surface, or one whose underlying rock exhibits abrupt changes in character; or effects to be expected in a tract visited by waves arriving simultaneously from different directions. Little is actually known of them, or of their practical importance. This western region of multitudinous mountain blocks with intervening alluviated valleys should yield valuable information regarding these phenomena.

We know already that some great earthquakes occur at the moment when fault-slips take place. Most students consider that the earth-jars are produced by the slipping. A few hold otherwise. The study of seismometric records, aided possibly by special studies such as that projected with microphones, promises to enlighten us as to the depth-limits, the size, and shape, and possibly the manner of development of the focal region. This should settle the point as to whether the earth-jars precede and release the slipping, or are consequences of it wholly or in part. An understanding of the mechanism of origination, if faulting is proved to be the *cause,* is a first essential to the discovery of "the laws according to which faults grow," which is so vital a practical and theoretical aim in seismic study. All these things are prerequisite to an adequate idea of the causation of earthquakes and their prediction.

Intensive studies and measurements of the *acceleration, amplitude, tempo, and intensity* and of the relationships of these to the geological character and the geographical position of any tract, are of high practical value and have definite bearing on the evaluation of the properties of the seismic waves and of the elastic earth.

This reviews some, but by no means all, of the work to be grouped under seismologic research. To conduct it effectively there must be theoretical studies guided by original imaginative conceptions; and statistical studies, experiments with precise physical instruments and routine work with the same, the invention and testing of these, and small-scale geological experiments to elucidate special principles or mechanisms;—all in order (*a*) to test and check the theoretical studies, and (*b*) to gather data upon which such studies may be founded.

CLASSIFICATION AND EQUIPMENT OF STATIONS

With regard now to the construction and equipment of stations of the different classes: It is difficult to formulate definite plans and wholly impossible to make a close estimate of costs in the absence of definite authority to proceed, acquire sites, make contracts, etc. Perhaps a *general* outline will suffice for the present discussion. More detailed statements of needed equipment and personnel must depend upon conditions; alternative plans, with rough cost estimates, can be formulated as desired.

A complete mensuration and registration of the motion of an earth particle in vibration, as during an earthquake, requires six seismometric devices: three to measure and register components of linear vibratory displacements, chosen usually in the N-S, E-W and up-down directions; and three to measure and register the oscillatory rotation of elementary planes about three rectangular axes, also usually chosen in the same directions. As yet, however, no mechanism has been devised to register satisfactorily the motion of rotation about the vertical axis. This is still a matter for experiment. Practical devices thus far register only five of the six components of motion.

Not to complicate too much the classification of earthquakes, we may think of them as far-shocks, near-shocks and local-shocks, and as strong, medium and weak in intensity.

The best of present types of seismometers register very well strong far-shocks, medium near-shocks and weak local-shocks, except that a recording surface which is moved along quite rapidly enough for far-shock registration proceeds too slowly for adequate local-shock registration and, probably, the recording of near-shocks would benefit by a slightly more "open" writing. Slight practicable changes in the recording mechanisms will obviate any difficulties that arise here.

The earth is not perfectly elastic, so the energy of a shock decays with distance. Any registration of weak far-shocks and the satisfactory registration of medium far-shocks is out of question so far. It goes without saying that seismometers should be improved in all possible ways,—but it is inutile to strive for the impossible.

The registration of moderately strong and medium near-shocks offers no present difficulty. The satisfactory registration of weak near-shocks is of great importance, but it can be accomplished only by sensitizing the seismometers to the highest possible degree.

For the highly necessary registration of weak local-shocks the best present types will suffice, if the time-rate of registration is increased. But medium local-shocks (and some strong near-shocks also) are too energetic, usually, for these sensitive devices. Some instrument of precision of less sensitivity and of less fragile character must be devised to register these. No satisfactory mechanism is yet offered, but this problem appears easy of solution nevertheless.

Strong local-shocks, that is, great earthquakes in and near their epicentral region, have never been registered seismometrically. It is hoped, of course, that some means of recording this motion will be worked out; but until greater success is attained, through experimentation, routine writing of such motion cannot be contemplated.

Hence, at stations of the first class, we should have instruments registering continuously five components of earth-wave motion, so sensitized and adjusted as to cover the range of seismic motion outlined above. This will require more than one set of instruments, at any rate for certain components and some classes of shocks. Contemplated improvements will, it is confidently expected, lessen the number needed. However, it will be desirable to install at such stations, and especially at the chief stations, instruments of different design and manufacture, in order to learn empirically how different masses and dimensions are affected, and thus what types appear best adapted for the *immediately practical* part of the work in this field.

All such instruments should be installed in subterranean chambers of suitable design.

Accurate time-clocks, or preferably chronometers, must be provided for time marking; and wireless time-signal outfits for automatic time-checks, settings and comparisons.

Specially constructed barometric and thermometric recording mechanisms of unusual sensitiveness appear most desirable.

At the chief station, besides apparatus and its places of installation, laboratory space and shops for machine construction must be provided; also library and office rooms, draughting rooms, photographic rooms, and possibly living rooms. For here must be the working center of a considerable scientific establishment.

Second-class stations should have a suitable subterranean chamber with three seismometers of the best all-round type, to measure the three linear components of motion, with time-keeping service,—all automatized so far as possible. Also seismometers for medium local-shocks should be installed at these stations. These equipments should be simplified and standardized in the most practicable way.

At standard stations of the third class a small subterranean vault with a seismometer registering one linear component only might be found to suffice, inasmuch as these stations are for control and study of the local problem only. A suitable time-keeping equipment would be necessary, with provisions for wireless time comparisons.

It seems probable that stations of the third class, and probably of the second class also, could be made to operate almost automatically for considerable intervals—say a week—thus allowing one traveling seismologist to oversee a chain of them. The mechanism could be so arranged that a person of ordinary mechanical attainments could perform the daily routine in a very brief time; and there is promise that even this service might be dispensed with.

As indicated above, certain stations, designated as third class, might advantageously be equipped somewhat more completely; so that these would take intermediate rank between standard stations of the second and third classes.

As with the equipment, so with the working force:—nothing specific can be indicated in the absence of a definite program. Even more than with the instrumental outfit, the personnel would have to be adjusted to the initial direction and scope of the undertaking. It, too, would better grow through experience from a relatively small beginning. So the need for *increasing resources* must be foreseen clearly, and adequate provision made.

Nevertheless, if improvements in contemplation can be carried through successfully, the entire program, or any part of it, can be taken up and continued satisfactorily with a much smaller scientific force and a much smaller routine outlay than would be required if such equipment as is now available had to be employed.

The work outlined above contemplates a specific attack within a localized area upon a definitely limited group of problems of immediately practical importance, apart from their ramifications in the fields of research. This would have no conflict with the sporadic work conducted by existing seismographic stations, nor with any broad statistical or regional studies in progress or in contemplation. It would aid, and not hinder, any work of this character.

In conclusion: This is no place to more than hint at possible contacts and extensions of such work; such, for example as educational efforts comprising lectures, short popular writings and so on, plans for coöperation with the Red Cross, the police and the military forces, when seismic disaster overtakes, and work with boards of insurance, and committees on legislation. Practical conclusions must be in hand before efforts of this kind could prove useful.

March 9, 1916.

THE EARTHQUAKE IN THE SOUTHERN APPALACHIANS FEBRUARY 21, 1916

By Stephen Taber

On February 21, 1916, about 6:40 p.m., eastern standard time, an earthquake occurred with its origin or origins in the southern portion of the Appalachian Mountains not far from the boundary between North Carolina and Tennessee.

The Monthly Weather Review for February 1916 contains a list of 86 places from which reports were received by the Weather Bureau. These places are located in North and South Carolina, Tennessee, Virginia, Georgia, Alabama, and Kentucky. A short note on the earthquake by Professor W. J. Humphreys was published in the *Monthly Weather Review* for March. It is accompanied by an isoseismal map of the region giving "the various places, [88], from which reports of this earthquake were received and the corresponding intensities as estimated by the observers." [1] Professor Humphreys gives the time of the beginning of the disturbance at the epicenter as about $23^{h}\ 39^{m}\ 17^{s}$ Greenwich civil time.

Immediately after the earthquake the present writer began to collect information concerning the intensity of the disturbance throughout the area over which it was felt. He was aided in this work by students in the University of South Carolina and by many others who courteously furnished information and assistance.[2] From the data thus obtained the writer was able to make estimates of intensity for 198 places; and since the estimates were all made by the same person, they should furnish a better basis for comparison than would be possible if each were made by a different individual. In the preparation of the accompanying map (see fig. 1) estimated intensities for a total

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[1] Humphreys, W. J.: "The Southern Appalachian Earthquake of February 21, 1916." *Monthly Weather Review*, 44, 154 (1916).

[2] The writer is indebted especially to Mr. W. S. McCallie, State Geologist of Georgia, who furnished a large number of newspaper clippings; Prof. H. E. Dennison, who aided in the collection of data from Tennessee; and Mr. Richard R. Sullivan, Meteorologist of the U. S. Weather Bureau, Columbia, S. C., who furnished much information concerning the distribution of intensities in South Carolina.

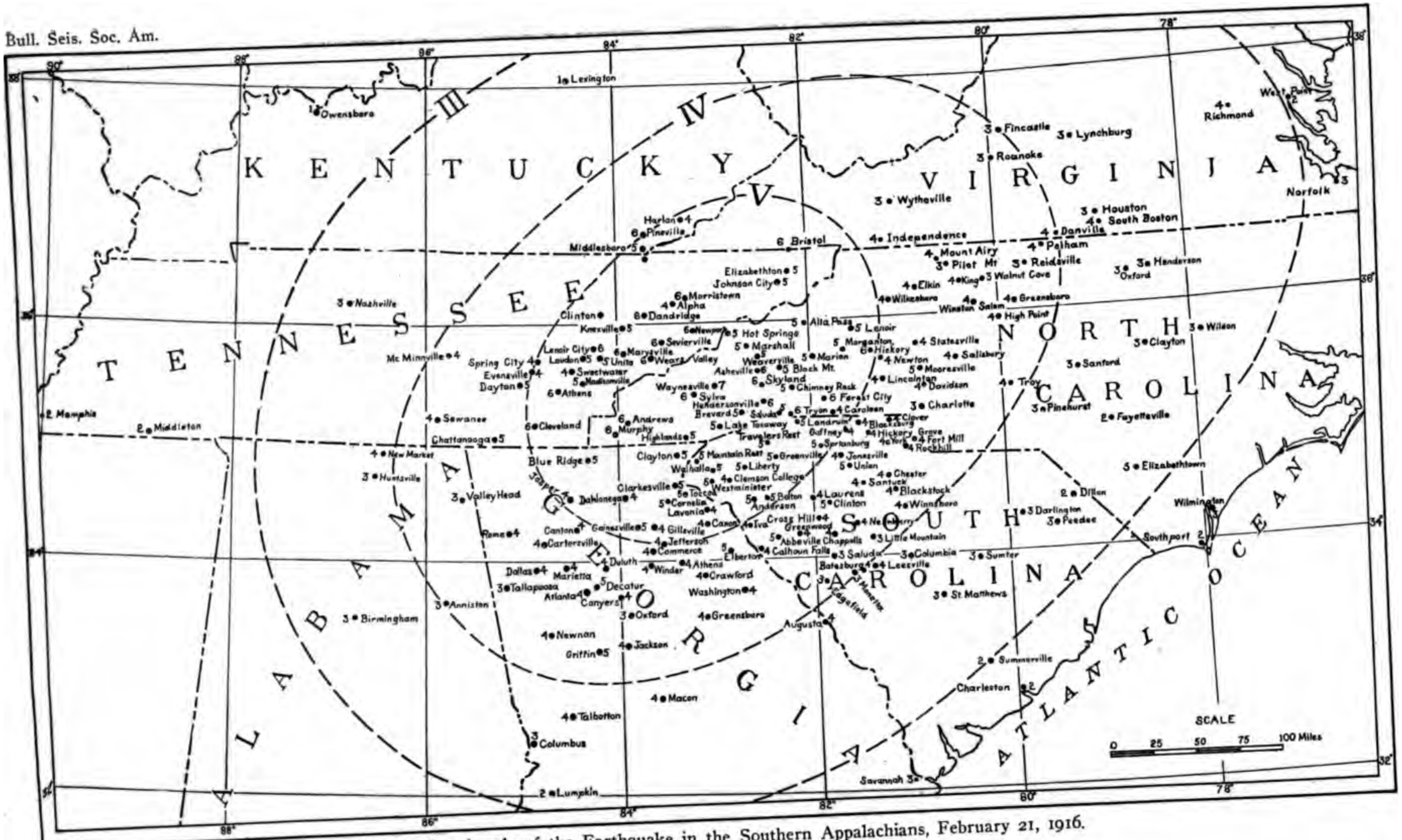

Fig. 1. Isoseismals of the Earthquake in the Southern Appalachians, February 21, 1916.

of 219 places were used. In the case of 21 of these places, located chiefly in North Carolina, the writer did not have sufficient data on which to base his estimates, and therefore used the intensities reported to the United States Weather Bureau by its observers.

The area of maximum intensity is located in a region that is sparsely inhabited, especially during the winter months, and the few small towns are widely scattered. For this reason the information from places in the epicentral region is not so complete as might be desired. The intensity seems to have been greater at Waynesville, N. C., than at any other town from whch reports were received. At this place many chimney-tops were thrown down, window-panes were broken in a number of houses, and people rushed into the streets badly frightened. Two shocks occurring in rapid succession were reported. The intensity, which was probably about VII in the Rossi-Forel scale, is described as violent, and several observers state that it was more severe than at the time of the Charleston earthquake of 1886. Because of insufficient data it is not possible to draw isoseimals VII and VI.

Isoseismal V (see fig. 1) is elliptical in shape, the major axis extending in a northeast-southwest direction, and the area inclosed is approximately 27,000 square miles. The center of this ellipse is located about ten miles northwest of Waynesville, in the neighborhood of latitude 35°35′N. and longitude 83°05′W. Professor Humphreys locates the epicenter near Skyland, N. C., latitude 35°30′ N. and longitude 82°30′ W. Within isoseismal V the shock was felt generally by everyone; at many places dishes were shaken from shelves and tables, water splashed out of pitchers and pails, and people ran from houses in fright. Damage to chimneys was reported from Newport, Marysville, Sevierville and Athens in Tennessee, and from Bristol, Virginia. According to newspaper accounts the walls of a hotel at Forest City, North Carolina, were cracked in four places. Fall of plaster was reported from Morristown and Knoxville, Tennessee; Bristol, Virginia; and Tryon, North Carolina. The reports from several places state that there was an increased flow from springs, and in some instances the water was made muddy. Sounds seem to have been heard generally wherever the intensity was above IV.

Isoseismals IV and III are also elliptical and approximately concentric with isoseismal V, but there seems to have been a decidedly more rapid decrease in intensity in the southwesterly than in the northeasterly direction. At Richmond, Virginia, which is about 340 miles northeast of the center of the ellipse formed by isoseismal V, the intensity was nearly IV. Here the shock was felt by many, although not by everyone. Two distinct tremors were reported, each lasting but a few seconds. Pictures were shaken from the walls in several houses, and a few pieces of bric-a-brac were knocked from stands or mantels and broken. At Birmingham, Alabama, and Columbus, Georgia, both of which are about 240 miles in a southwesterly direction from the center of isoseismal V, the disturbance caused no damage, and was felt by comparatively few.

The earthquake was felt at points along the coast from Savannah, Georgia, to Norfolk, Virginia, the intensity varying from II to III. Norfolk, where the intensity was III, is about 390 miles N. 75° E. from the center of the ellipse formed by isoseismal V. Going inland, the shock was felt as far west as Memphis, 400 miles from the center of isoseismal V. So far as the writer is aware, this is the most distant point reporting the shock as felt. Dr. C. W. Davis of Memphis, who was on the third floor of a building at the time of the earthquake, states that the vibrations were considerable, causing windows to rattle. The disturbance was noticed by many people in West Memphis, but resulted in no damage.

It is significant that this earthquake with a maximum intensity of about VII was felt at points approximately 400 miles from the epicenter and on opposite sides of it, while the San Francisco earthquake of 1906 with its extremely high epicentral intensity was not felt at any point more than 350 miles from the origin. Although the earthquake of February 21st was sensible at such relatively great distances from the origin, it was not recorded instrumentally at stations unusually far away. According to Professor Humphreys, the shock was recorded instrumentally at Harvard University (about 800 miles away); Canisius College, Buffalo; University of Kansas, Lawrence; and at several other stations located closer to the origin.[3]

With the limited data at hand it is not possible to determine the exact area over which the disturbance was sensible, but it must have been not less than 300,000 square miles, and may have been considerably more. Considering the relatively low intensity reported from points in the epicentral region, this area is unusually large. The area within which a shock is perceptible, is commonly taken as a rough measure of the total energy set free by an earthquake; but this area varies with the character of the rocks through which the vibrations are propagated, as well as with the total amount of energy and the rate at which it is liberated during the disturbance. Therefore, in comparing the energy of earthquakes, especially when their maximum intensities are relatively low, it is preferable that the comparison be made between earthquakes occurring in the same region, or, at least, in regions where the elasticity, density and structure of the rocks are similar. In recent years a number of earthquakes have occurred in the Southern Appalachian region, and, fortunately for our present purpose, one of them has been studied in some detail.

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[3] Loc. cit., 154.

The South Carolina earthquake of January 1, 1913, with epicenter near Union, had an intensity of about VIII, but the shock was sensible over an area of only 43,000 square miles.[4] This means that the earthquake of February 21st, although it had a lower maximum intensity, was felt over an area approximately seven times as great as the South Carolina earthquake.

The outer isoseismals for both of these earthquakes are elliptical, with their major axes extending northeast and southwest. In both instances the isoseismals extend further in the northeastern direction than in any other, thus indicating that in this general region there is for some reason a better propagation of earth vibrations in that direction. In both cases the isoseismals tend to become less circular and more elongated in form the farther they are from the origin. This is probably explained by the fact that the rock structure throughout the Southern Appalachian region runs in a general northeast-southwest direction. Waves propagated parallel to the rock structure undergo less reflection and refraction than waves propagated in other directions, and therefore are not so quickly dissipated.

All of the recent earthquakes in this region are unquestionably due to the differential displacement of rocks under strain, although there may be no evidence of faulting on the surface. The displacement that resulted in the earthquake of January 1, 1913, was probably very limited in its linear extent, for the inner isoseismals were circular in form; and the small area inclosed by these lines, together with the rapid decrease in intensity with distance from the epicenter, indicates that the locus of the disturbance was comparatively near the surface. The lower maximum intensity of the earthquake of February 21st as measured by the Rossi-Forel scale, may be due to a greater depth of the focus. But greater depth is not sufficient to explain the enormous difference in the areas affected, and it is possible that the lower intensity is largely or in part due to a smaller maximum stress in the area that was under strain and perhaps to a slower adjustment of the strains.

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[4] Taber, Stephen: "The South Carolina Earthquake of January 1, 1913." *Bulletin of the Seismological Society of America*, 3, 6-13 (1913).

The size of the area that is sensibly shaken depends on the total mass displaced during the adjustment of strains as well as the magnitude of the stresses relieved. The distribution of intensities in the epicentral region of the February earthquake is not such as to indicate a displacement along a fault of any considerable linear extent. The greater the distance that the strained area extends back from a fault, the greater must the displacement be in order to relieve a given stress. A large displacement, however, along any fault plane intersecting the surface would probably have formed noticeable fissures, and nothing of this sort has been reported. The adjustment of strains may have been distributed along more than one fault, for two distinct shocks were felt over most of the region affected. This theory is supported to a limited extent by the distribution of intensities, and there may have been two epicenters, one on each side of the Great Smoky Mountains; but the incompleteness of data from the epicentral region makes a definite answer to this question impossible.

A number of earthquakes, mostly of low intensity, have occurred in the Southern Appalachian region within the last few years, but they have been rather widely distributed, and do not seem to have been any more frequent in one locality than another. The South Carolina earthquake of January 1, 1913, has already been mentioned, and two earthquakes with widely separated epicenters were felt in eastern Tennessee on March 28th and April 17th of the same year.[5] The Georgia earthquake of March 5, 1914, which had an intensity of VI near its origin, about thirty miles southeast of Atlanta, was felt over an area of nearly 95,000 square miles, and on March 6th a slight tremor was felt at Chester, South Carolina.[6] An earthquake was recorded at Bristol, Tennessee, January 14, 1915, at 9:20 Greenwich civil time, the intensity being given as III-IV.[7] On October 29, 1915, at about 1:25 a.m. E. S. T. (6^h25^m Greenwich) an earthquake was felt at several places in Buncombe and Madison counties, North Carolina. The origin was probably not far from Marshall, latitude 35°45′ N., longitude 82°40′ W., where the intensity was about V. Many people were awakened at Marshall and at Asheville, fifteen miles southeast. The shock was sensible over an area of approximately 1,200 square miles, but because of the early hour the information is far from complete.[8]

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[5] Gordon, C. H.: "Earthquakes in East Tennessee." *Bulletin of the Seismological Society of America*, 3, 191-194 (1913).

[6] Taber, Stephen: "Earthquakes in South Carolina During 1914." *Bulletin of the Seismological Society of America*, 5, 96-99 (1915).

[7] Reported by B. F. Sperow under non-instrumental earthquake reports in *Monthly Weather Review*, 43, 40 (1915).

According to newspaper accounts, six distinct earthquake tremors were felt at Anderson, South Carolina, latitude 34°30′ N., longitude 82°40′ W., on March 2, 1916. The first occurred at two minutes past midnight (5^h02^m Greenwich) and was followed by four others at intervals of about thirty seconds, while the sixth and strongest tremor was felt about two minutes after the fifth. The tremors were accompanied by a rumbling noise. They caused windows to rattle, but resulted in no damage, and few people were awakened. On August 26, 1916, about 19^h35^m (Greenwich), an earthquake occurred in western North Carolina with its epicenter approximately at latitude 39° N., longitude 81° W.[9] The highest intensity (V, R.-F.) was reported from Statesville and Taylorsville, and the area sensibly affected was probably 4,000 square miles or more.

Alabama and neighboring states were disturbed by an earthquake on October 18, 1916, about 22^h04^m (Greenwich). According to newspaper accounts the intensity seems to have been greatest near Birmingham, where windows were broken and many chimneys thrown down. Most places report two distinct shocks. These shocks were felt by a few people in Columbia, South Carolina (intensity about II, R.-F.), over 300 miles from Birmingham. The newspapers also report shocks at Birmingham on October 22d and November 4th. The latter disturbance, which was the more severe, occurred about 12^h15^m (Greenwich), and the reports state that china was knocked down in several houses.

It is, of course, impossible to draw general conclusions from a list of earthquakes, probably incomplete and extending over a period of only four years. All of the information now available, however, seems to indicate that seismic activity is moderately high in the Southern Appalachians as a whole, although there is probably no single fault in the region that is especially active at the present time.

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[8] Personal communication from Dr. Harry Fielding Reid, November 17, 1916.

[9] Finch, R. H.: "The North Carolina Earthquake of August 26, 1916." *Monthly Weather Review,* **44**, 483 (1916).

The earthquake of February 21, 1916, had its origin near the western boundary of the Appalachian Mountain Belt. The center of the ellipse formed by isoseismal V falls in the southeastern corner of the Mt. Guyot topographic sheet of the United States Geological Survey. While this quadrangle has not been mapped geologically, all of the adjoining quadrangles with the exception of the Cowee sheet on the south have been mapped, and the geologic folios published.[10]

The Appalachian Mountains occupy a narrow belt which begins in eastern Alabama and extends northeastward, broadening to its greatest width of about seventy miles in North Carolina, where the highest elevations are found. In western North Carolina near the Virginia line the Blue Ridge forks, the Unaka or Great Smoky Mountains branch off toward the southwest, while the Blue Ridge proper continues in a more southerly direction. The Unaka mountains are higher and more rugged, but not so continuous as the well-defined Blue Ridge. The triangular area lying between these ridges is occupied by many short ranges and groups of mountains, some of which are merely spurs extending out from the principal ridges. To the southeast the Blue Ridge is flanked by the Piedmont plateau, while on the northwest the steep slopes of the Unaka ridge descend to a broad valley, occupied by the Tennessee River and its tributaries.

The rocks in the Appalachian Mountain division are for the most part crystalline, and consist of metamorphosed sediments and igneous rocks. In the central and southeastern part of the belt they are chiefly pre-Cambrian in age, while in the Great Smoky Mountains they are Cambrian. The contact between the pre-Cambrian and Palezoic rocks is very irregular, with many outliers and inliers, but in a general way it roughly parallels the North Carolina-Tennessee state line. It is frequently, though not always, marked by the presence of faults. This contact crosses the southeast corner of the Mt. Guyot Quadrangle close to the center of isoseismal V, as located on the accompanying map. The rocks that are sedimentary in origin furnish evidence of much folding, while thrust faults, usually having a southeasterly dip, are common. Most of the faults dip at steep angles, but a few are rather flat, and displacements of several miles have been measured.

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[10] The geologic mapping in this region was done by Mr. Arthur Keith. The quadrangles adjoining the Mt. Guyot sheet, for which geologic folios have been published, are as follows: Nantahala, No. 143; Knoxville, No. 16; Maynardville, No. 75; Morristown, No. 27; Greenville, No. 118; Asheville, No. 116; and Pisgah, No. 147.

In many of the folds adjustments have taken place along the planes of bedding and schistosity. Some of the recent earthquakes may have resulted from adjustments of this kind.

The topography, especially of the interior ranges, is controlled chiefly by the circumstance of drainage rather than by the structure. With few exceptions the general strike of the faults, as well as the schistosity of the rocks and the contacts between different formations, is in a northeast-southwest direction; but the minor ranges cut directly across this strike quite as frequently as otherwise. Therefore, while the recent earthquakes in this region are tectonic in origin, the crustal movements now going on are of such a nature and take place so slowly that the topography is not directly influenced by the faulting, as is the case in many of the younger and rapidly growing mountain ranges which are the loci of much greater seismic activity.

Although there are many faults in the Southern Appalachians, there has probably been very little displacement along most of them in recent geologic time. In other words, they may be classed as inactive faults. The crustal movements that have taken place in the Appalachians since the Cretaceous period and to which the present height of the mountains must be largely attributed, are in the nature of a slow differential uplift, accompanied by a gentle warping or dome-like arching of the entire region. A movement of this kind probably results in the development of strains over a broad area, although these strains may in general be relieved by relatively small displacements. It is not unlikely that the recent earthquakes in the Southern Appalachians are due to a continuation of this slow gradual elevation of the region that has been going on intermittently in recent geologic time.

University of South Carolina,
Columbia, South Carolina,
November 19, 1916.

EARTHQUAKE INTENSITY SCALES

By Count de Montessus de Ballore,
Director of the Seismological Service of Chile.

Seismologists in charge of seismologic services that cover large areas have no more difficult and complicated problems to deal with than that of earthquake intensity scales. I am just now especially impressed with these difficulties on account of having met them in my personal experience after having established the Chilian Seismological Service. Before discussing the subject proper, however, I venture to speak of that personal experience, for I am confident that it is worth more in this connection than any abstract reasoning.

With the exception of a single point, namely, the Santa Lucia Hill, on which the Seismological Observatory is built, and the bed rock of which is a solid trachytic rock, the great plain on which the city of Santiago stands is everywhere formed by thick clayey sediments deposited by the Mapocho river on its emergence from the San Cristobal – Santa Lucia defile or narrow pass, so that the city is built upon a large alluvial cone. Only in the most western suburbs of the city are there some sandy and less coherent deposits. Besides, throughout the city the building methods and the materials of construction are equally bad and far from being earthquake proof. In consequence of this uniformity of external circumstances, it might be expected that the effects of earthquakes on the human senses and on buildings would be uniform, and that it would be very easy to estimate exactly the degree of intensity of an earthquake by means of the Rossi-Forel, Mercalli, or any other more or less analogous scale. However, and in spite of my being an old seismologist and able to speak from a wide experience, I confess that, in the midst of the numerous and contradictory records I receive from all parts of the city, I find myself in the most perplexing doubts about the exact degree of intensity, and this happens every time there is an earthquake here. The same thing happens almost every day in connection with the records received at the central office from the observers all over the country. At the time of the great Chilian earthquake of August 1906, I found the same difficulties in attempting to estimate the intensity in more than 400 places by means of the answers made to a very simple questionnaire distributed all over the country soon after the disaster. From the answers received I could not draw the isoseismal curves on the map with satisfactory scientific accuracy.

The macroseismic observations of the Chilian earthquake service are made by volunteer observers and by numerous public officials, who are scattered as uniformly as possible over the whole country; the public officials are professors in state lyceums, schoolmasters, railroad stationmasters, lighthousekeepers, and telegraph operators. Even for the more skilled of these observers, I have been obliged to abandon the idea of their determining the intensity of the earthquake shocks they feel; and so some months ago I furnished them a list of the seismical effects on the human senses, furniture and buildings, in the order in which they appear in the ordinary earthquake scales, but after having taken off the grades. In other words, it is for the Santiago central office to deduce the intensity from the effects which the observers have recorded.

There is no ground for thinking that our Chilian public officers are any less intelligent, careful, or conscientious in their professional duties in connection with the earthquake observations, than those of any other civilized country, and we cannot therefore believe that such an organization ought to be considered as having failed. I understand now the numerous and serious difficulties I have always encountered every time I have had to study the records of great earthquakes as they are reported in the seismic catalogues or special memoirs.

The officers of the meteorological service being accustomed to making scientific observations, it seems possible that they could also be commissioned to make earthquake observations in all countries in which meteorological stations are numerous enough, as for example in the United States of North America. But as far as the use of the earthquake intensity scales is concerned, the observers of the Chilian Meteorological Institute have not, as a rule, been any more successful than the other public officers.

These difficulties do not arise from the carelessness of the persons who make the earthquake observations; they lie much deeper, for the estimate of seismic intensity is the result of many variable factors, which have no direct relation to the natural phenomena themselves. These factors are the turn of mind and temperament of the observer, the coherence of the subsoil, the mode of construction and nature of the buildings, etc. All these disturbing influences are well known, so that it is unnecessary to say more about them in this place. But I can and do affirm, that after having located on the map the earthquake intensity grades which have been estimated in a great number of places after a severe or destructive earthquake, it is impossible and misleading to trace isoseismal curves. The network of these estimates is really inextricable, in spite of their having been made accurately. With these facts in mind, I am very far from admiring the fine geometrical forms of the isoseismals we find in all the great earthquake monographs, for these curves can only be inferred from rough and erroneous methods of approximation. As for the Valparaiso earthquake of 1906, I am quite unable to draw the isoseismal curves.

It is easy to account for this difficulty, which, in my opinion, is beyond remedy. When meteorologists draw their isobars or isothermic curves, they begin by reducing the temperatures or the atmospheric pressures to sea level by means of appropriate formulae. In other words, they calculate these elements according to what they should have measured in places equally distant from the earth's center. But as regards the earthquake observations of intensity, we cannot conceive of any method or formula which would enable us to reduce all estimates to uniform exterior circumstances, that is to say, to uniformity of subsoil, rigidity of buildings, temperament of the observers, etc. The mere enumeration of these requirements shows clearly the illusiveness of such an attempt.

What has seismological science to lose in consequence of not drawing these isoseismals? For my own part, I have been obliged to abandon this classic method, notwithstanding the general use of these curves by almost all the seismologists. In spite of the paradoxical appearance of my opinoin, I do not think this loss will be a very important one. For what purpose have we been in the habit of drawing these curves? We have sought to deduce from their forms and positions on the maps the tectonic or geological features on which the movement has let loose the earthquakes we are investigating. But if we have a clear idea of the local geology, the geological accident, or phenomenon above alluded to, will be shown either by an appreciable and measurable movement on the fault or thrust plane, or by evidence of its having been the seat of the more violently shaken places. In both cases, and without drawing isoseismals, we can solve the principal problem of geological seismology that we have to deal with. As for the determination of the areas in which it is necessary to build earthquake-proof edifices, there should be no great difficulty, for they are defined by the damage observed.

It is a noteworthy fact that John Milne almost never made use of intensity scales, nor did he delineate isoseismal curves in his many seismological papers; and it was only for other purposes that he established a scale of three degrees for the destructive earthquakes.

In the same manner Omori established a more complicated scale for destructive shocks; but he based his scale upon the maximum acceleration of a terrestrial particle, and its results were only theoretical, so that it cannot be used for drawing isoseismal curves. Furthermore, in the very valuable papers published during the past thirty-five years by the Imperial Earthquake Committee of Tokyo, the seismic intensity is generally indicated by means of the very vague expressions of feeble, strong, and destructive, and yet the scientific value of these memoirs does not appear lessened thereby.

Taking into consideration all these circumstances, I think that only the following outlines should be delineated on maps:

1. The curve or rather the polygon which defines the area of perceptible shaking.
2. The places of maximum intensity or of severest damages, but only when these observations can be made accurately.
3. The limits of the area of damage, which in all cases can be readily determined with great precision.

These outlines should never be delineated approximately, however irregular they may appear.

As to the expressions so frequently used in the records, such as alarm, fright, terror, panic, etc., they should be definitely forbidden, for they have no precise or uniform meaning, but depend upon observers and localities. Earthquakes of equal intensity might readily be estimated as dreadful in New Orleans but only insignificant in San Francisco. Every seismologist who has any acquaintance with seismological reports and records has no doubt on this point.

For Santiago, I can affirm that the observation "felt by persons walking" corresponds to a greater intensity than the record "felt by every one." This seems to be due to the more or less coherent nature of the subsoil at Santiago.

As to the third degree of intensity of the proposed scale, I cannot accept as trustworthy the expression "appreciable direction." Such observations should be suppressed as delusive, for, as is now well known, these physiological sensations result only from the direction and position of the main walls of the house in which the observer stands.

It is not less known, also, that the apparent duration of the sensible macroseismic movement depends in a great degree on the distance of the place of observation and on the nature of the subsoil, which is set in vibration during a period of time that varies greatly, so that the expression "appreciable duration" is meaningless in estimating intensity.

The attention of readers is asked to the instructions given to the observers of the Chilian Seismological Service and above all to the fourth page.

Santiago, Chile, January 14, 1916.

THE COSTA RICA EARTHQUAKE OF FEBRUARY 27, 1916[1]

By Don J. Fidel Tristan,
Secretary of the Centro de Estudios Sismologicos,
San José de Costa Rica.

There were available for the study of the earthquake of February 27th, 1916, seismograms of the Seismologic Service of the National Observatory, in charge of Rafael M. Tristan, engineer. Unfortunately the seismoscope has not been working for some time past because the electric battery is entirely exhausted, and the special paper for the cylinder has been used up. Help also was obtained from telegrams received at the observatory, while the information furnished by the press was quite complete, though much of the data published have no scientific value.

Former Shocks.— Since the earthquake of November 29, 1915, at 11:08 p.m., with an intensity of IV, there was registered one small shock on December 12th at 8:25 p.m., with an intensity of II. From that time, and throughout the whole month of January of the present year, there was complete quiet,—no account being taken of microseisms. The same cannot be said, however, of the month of February, for which we have no seismoscopic records. On the 23d a shock with an intensity of II was felt, and I heard from Punta Arenas that on the 25th at 9 p.m. another shock of short duration was noted.

At 2:47 p.m. on February 27, 1916, there was felt in almost every part of the Republic a violent and prolonged earthquake, with a larger amplitude than had ever been recorded before. The movement lasted two minutes and thirty seconds, while the perceptible movement lasted for fifty seconds. According to the seismogram of the Ewing machine, after the tremor which lasted twenty-six seconds there followed a swaying with a wide amplitude in a northwest-southeast direction that increased gradually until one could see the oscillatory and undulating swaying of buildings and trees. The slowness of the vibrations allowed houses and other things to follow the movement without losing their balance, and for that reason loose objects hardly moved from their positions, nor was any damage done to the buildings of the capitol or in other places on the Atlantic side.

The very pronounced up and down motion produced on most persons a peculiar sensation of nausea that prevented them, for the time being, of taking note of what was going on. But as no other strong shock had been felt during the day, the majority of the people were surprised at their sensations, and it was only several seconds later that they realized that they had to do with an earthquake, for they had attributed the nausea to other causes. In some cases the nausea was violent enough to produce vomiting. The water in the streams and gullies was stopped and dashed over both banks to a considerable distance, and in many cases it was muddied by the earth from the sides.

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[1] Translated from *La Gaceta,* Diario Oficial, San Juan de Costa Rica, 18 de marzo de 1916.

Data from the Observatory.— This shock was registered at the observatory at 2:47 p.m.; intensity VI. The total duration of the shock was 2m. 30s.

The principal direction of the oscillatory movement was northwest-southeast.

The maximum amplitude of the oscillatory movement was in the north-south component 41 mm.

The maximum amplitude of the east-west component was 36 mm.[2]

Tremor.— The tremor lasted 26 seconds, and was composed of a series of very rapid vibrations, with their greater amplitude east-west, accompanied by a marked tremular movement.

Principal phase.— After the four very strong oscillations there followed a rocking movement of very great amplitude in a marked northwest-southeast direction, and this rocking, produced by enormously big waves, and 19 seconds after the principal phase, increased to such an extent that the needle registering the east-west direction jumped off the disc. The balancing lasted for 5 seconds. The north-south needle continued to register the rather slow rocking movement of wide amplitude. The tremular movement was also very marked, and had a maximum that caused the horizontal needles to make a series of dots. This phase lasted 50 seconds, and was generally observed by the public. The great rocking movement and the tremular motion caused the nausea felt by many persons.

Final Phase.— The final phase lasted for 74 seconds, and was characterized by a tremular movement that lasted still longer. After the termination of this phase the tremular movement lasted until the disc stopped revolving. This earthquake, of distant epicenter and affecting a very wide seismic area, must have included a large part of the whole country.

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[2] Considerable more data concerning the various phases of the shock and amplitudes of the movements are given, but there appear to be some typographical errors, so that it is not possible to translate with certainty.—*Ed.*

At 3:34 a shock was registered with an intensity of II, and at 4:31 another was recorded with an intensity of II.

The area of the earthquake.— In the northern part of the Republic of Costa Rica the shock was very intense on both coasts, but rather stronger on the Pacific side. It is reported to have been felt at Managua, Nicaragua, though no damage was done. At Limon, on the Atlantic coast, the movement was very decided, as it also was in the central plateau. To the south its limits cannot be determined for lack of information, but it is probable that it was felt in the Republic of Panama. We have as yet no report of its having been registered at other seismologic centers.

Intensity.— In San José the intensity corresponded to VII of the Rossi-Forel scale. It increased toward the Pacific, and at Alajuela and San Ramon some buildings were damaged. In the northwestern part of the province of Guanacaste the intensity reached IX, with partial or total destruction of some buildings. At Limon the intensity was IV.

The region affected.— The data obtained in regard to the intensity have no value, for the majority of our correspondents are not acquainted with the Rossi-Forel scale. It is therefore impossible to draw the isoseismic curves and to determine the epicentral region. It is evident, however, that the intensity increased toward the northwest on the Pacific coast, and that it was lower toward the Atlantic. The damage done was greater in the towns in the northwestern part of the Nicoya peninsula. These facts enable us to fix upon the epicentral region as a zone included between the great Culebra bay, Cape Santa Helena and Punta Gorda. Sardinal, seven kilometers from the coast, suffered severely; and at Santa Cruz, thirty-three kilometers inland, the towers of the church were thrown down. At Coco the shock was very severe, and cracks were made in the ground.

The epicenter.— In accordance with the foregoing facts the epicentral zone, which was very large, extended into the sea, and for that reason cannot be determined, because at sea no traces of the movement are left, and elsewhere observations are very scarce. The data received go to show that in Coco and Sardinal the intensity was above IX, which shows that these places were inside of the epicentral area, whose center or epicenter was under the ocean at some distance from the coast.

With the Ewing seismogram one can determine approximately the position of the epicenter. Omori's formula gives a distance of 227 km. from the observatory. From San José to the end of Coco Bay is

194 km. in a straight line, so that the epicenter was 33 km. from the coast. Bearing in mind the difficulty of locating precisely the prephase or tremor of the principal phases with the Ewing seismograph, that distance should be less, and may be set down as approximately 25 km. The real epicenter is not a mathematical point, but a zone that may have many forms, whose dimensions in this case are not known. In view of the large area affected, it is to be assumed that the focus or hypocenter of this earthquake must have been at a great depth.

Earthquake sounds.— So far as my investigations go, no sounds of any kind were heard on the central plateau, either before or after the earthquake. At Santa Cruz Sr. Lauro M. Leal says that the earthquake was preceded by "a loud cavernous rumbling"; and Sr. I. Ibarra, who was sailing in front of the Papagayo at the time, says that "one seemed to hear various strange sounds different from those produced by the wind." None of the other communications received mentions noises. It is evident therefore that these sounds were produced only in the epicentral zone.

The nature of the phenomenon.— The idea that this earthquake had any relation to volcanic phenomena cannot be admitted, for up to this time no news has been received of any volcanic manifestation. On the Nicoya peninsula there is no active volcano, and those that do exist in the northern volcanic range have shown no signs of increased activity. On the other hand if it were a submarine eruption it must have been a formidable one to have produced such an earthquake, and there is no evidence of such a phenomenon. In the present instance volcanic action is entirely discarded, and if anything of the kind manifested itself it should be considered as an effect and not as a cause. The great earthquake of the 27th and those which immediately followed it must be regarded as having a tectonic origin, that is, with distinct foci or hypocenters at great depths and at some distance from the coast. In spite of the great violence of the shock equilibrium was restored very quickly, which is not to be understood as meaning that this phenomenon will not be repeated in the same place.

The 21st of July, 1900, at 3:14 p.m., there was felt in the same region a long and strong shock that caused considerable damage. The seismic period lasted nearly two months. The shock of February 27th was very like that of 1900, and it certainly had the same origin.

Another unstable zone which is not included in the Geografia Sismologica of Count de Montessus de Ballore, should thus be added to the seismologic map of Costa Rica.

SEISMOLOGICAL NOTES

Awakening of two old volcanoes in Luzon, Philippine Islands.—On the 8th of November, 1915, frequent earthquake shocks began to be felt on and around the old Isarog volcano, with some occasional noises; many landslides were also produced in the outer slopes of the mountain.

These disturbances repeated themselves two or three times at long intervals until the 10th of January, 1916, and gave rise to the rumor that the volcano was either in actual eruption or threatening a tremendous outburst. As the whole mountain is thickly wooded, even inside of the crater and the great breach looking toward the north, nobody could distinctly see if there issued any fumaroles. At last the earth-tremors ceased and the fears were appeased. There do not exist any records in the history of the Archipelago of recent outbursts of this volanco, which for centuries has been dormant: it rises in Ambos Camarines province, some thirty-five miles north-northwest of Mayon volcano.

Soon after these disturbances in the Isarog had been nearly forgotten, reports came that the Bulusan volcano was in eruption since the 18th of January.

During two or three days rumblings were heard and earth-tremors felt in its vicinity; ashes and lapilli fell at distances of ten miles in the southwest direction, due to the northeast wind then prevailing. As the top of the volcano remained constantly covered by rain-clouds, no observation was made about the vent where the eruption took place. When the sky cleared, only the fumaroles were to be seen issuing forth, but not with much greater intensity than before the eruption.

To notice if light earth-tremors were yet produced in the volcano as indicators of accumulating energy, the Weather Bureau set up a seismograph in one of the nearest towns more affected by the last outburst. The absolute absence of local tremors during the three months following the small eruption was considered as an indication that for the present time there is no danger of new and greater eruptions.

This volcano lies south-southeast of the Mayon volcano in the province of Sorsogon, and at a distance of about forty-three miles.

from the former. It belongs to the volcanic system of southeastern Luzon, represented by the Bulusan, Manito cones and hot springs, Mayon, Iriga cone, Buhi hot springs and Isarog volcano, all ranged on a S.SE-N.NW line. Some old reports about small eruptions of the Bulusan, to be found in historical papers, are very vague and dubious. It had been seen always in a sulphataric state represented by small fumaroles issuing near its irregular top. There is no regular crater at present; but the alternate layers of old lava and ejecta visible in the ravines deepened by the water, show that formerly it had a better shaped conical form. Near it stand many different minor cones similarly deformed by denudation.

M. Saderra Masó.

Distant earthquakes felt in the Philippines.— The New Guinea earthquakes which occurred on January 13, 1916, registered in the Observatory at $6^h23^m34^s$ and $8^h25^m46^s$ (G. m. t.), presumably were perceptible on the eastern part of Samar and Mindanao islands. At about the same hours perceptible shocks were felt at Borongan (E. Samar), and Butuan (E. Mindanao); in the last station they were noticed at the same time a Wiechert seismograph registered the said two distant quakes. Were these light shocks secondary earthquakes or direct waves from New Guinea perceptible at such a distance? Both the eastern coasts of Samar and Mindanao are bordering the "Great Philippine Deep," the deepest so far known, consequently in a very unstable position.

M. Saderra Masó.

Volcanic eruption in Mexico, August 21, 1916.— A volcanic eruption is said to have occurred the night of August 21st in Baja California, about twenty-five miles south of Calexico, Cal. Mud and steam were thrown high in the air and spread over a large area in the vicinity of Black Butte.

Eureka, Cal., August 23, 1916.— A sharp earthquake was felt at Eureka, Cal., the morning of August 23d. It was the severest shock felt in that region since that of April 1906. It was felt throughout the northern part of Humboldt county; at Ferndale it lasted only a couple of seconds. No damage was reported.

Cairo, Ill., August 24, 1916.— Shortly after five o'clock, on August 24th, the city of Cairo, Illinois, was shaken by an earthquake. No damage was caused; a low rumbling sound accompanied the tremor.

Formosa Island, August 28, 1916.— A violent earthquake occurred near Mount Morrison in the southern part of the Island of Formosa on August 28th. Five hundred houses are said to have been destroyed and thirty persons killed.

San Juan del Sud, Nicaragua, September 23, 1916.— A heavy shock occurred in the morning of September 23d at San Juan del Sud, Nicaragua. No reports in regard to damage have been received.

Southern California, September 29, 1916.— About eight o'clock p.m. on September 29th, a slight earthquake shock was felt through the extreme southern part of California, extending from the Imperial Valley westward to San Diego.

An Appalachian earthquake, October 18, 1916.— Shortly after 4 p.m., on October 18th, a sharp earthquake was felt throughout northern Alabama, northwestern Georgia and western South Carolina, east Tennessee, and as far north as Louisville, Kentucky. Dr. Stephen Taber reports that the intensity at Columbia, South Carolina, was about III of the R.-F. scale. The epicenter seems to have been in northeastern Alabama, where the intensity was close to VIII.

Our colleague Dr. C. H. Gordon, of the University of Tennessee at Knoxville, has kindly furnished us the following account of it.

> The southern states, including Alabama, Georgia, Tennessee, and Kentucky, were visited by an earthquake in the afternoon of October 18th. The center of the disturbance was in northeastern Alabama and northwestern Georgia. The quake occurred about 4 o'clock in the afternoon, and in some places seems to have consisted of two distinct shocks, though in others only one was reported.
>
> *Georgia.*— Two distinct earthquake shocks were reported from western and northwestern Georgia. Frame buildings were shaken and chimneys knocked down in various places. Many ran from their homes, but no serious damage was reported. Some of the reports state that the first shock was heavier than the second, but in other instances this was reversed. Two distinct shocks were reported to have been felt in Columbus and Macon, Georgia.
>
> *Alabama.*— In Montgomery, buildings were shaken by very distinct shocks which lasted about five seconds. The local weather bureau states that the shock came from the northwest and was of intensity V. There was no damage reported. At Talladega large buildings and dwellings were shaken, and hundreds of people ran from their homes. At Anniston two distinct shocks were felt, being so noticeable that a

murder trial which was in session in the county courthouse was abruptly halted for a few minutes while the judge, jurymen and spectators ran from the building. The shock was felt in other towns in this vicinity, but no damage was reported. At Birmingham the quake was the most severe that city has ever experienced. There were three sharp, distinct shocks, separated by brief intervals. The quakes caused great excitement, but very little damage other than broken windows and fallen chimneys was reported.

Tennessee.— At Chattanooga the shock lasted from four to five seconds, and was distinctly felt throughout the city. One woman was almost thrown from her chair, according to reports. Slight shock was felt in Nashville, but no damage was reported. A number of persons in Knoxville reported a slight shock lasting a second or so. As it was raining there at the time, the disturbance was not generally noticed at Knoxville.

Kentucky.— A slight shock was felt in portions of Kentucky, especially in the vicinity of Louisville. There buildings were rocked in the business district, while in the outlying districts pictures were knocked down and chinaware broken.

Middle Japan, November 29, 1916.— Cablegrams from Tokyo, Japan, dated November 29th, report that "considerable damage has been caused by an earthquake in middle Japan. Many houses have been destroyed in Kobe, Osaka, and Kyoto." The date and hour of the shock are not given. It is said that the railway station at Kyoto was damaged, and that several persons were hurt by falling walls and roofs in that city and in Kobe.

Santo Domingo, December 1, 1916.— Two severe shocks were reported from Santo Domingo as having occurred "last night." No damage was done.

San Luis Obispo, California, December 1, 1916.— Four shocks in rapid succession were felt at San Luis Obispo, Cal., at 3 o'clock p.m., December 1st. No damage was reported.

Lassen Peak, California, December 10, 1916.— Lassen Peak, the volcanic cone described by Mr. J. S. Diller in the ***Bulletin of the Seismological Society of America,*** vol. IV, pp. 103-107, is said to have burst into eruption again at 4 p.m. on December 10th, throwing out ashes.

Lava rising in Kilauea, Hawaii, December 14, 1916.— A telegram received from Professor Jaggar, director of the Hawaiian volcano observatory, says the lava is rising in the crater of Kilauea. At the time of his message it was within 140 feet of the rim and rising rapidly. Professor Jaggar's report published in July 1916 says the surface of the lake was 482 feet below the rim on July 18th. During the week ending July 26th, the lava had risen at the rate of four feet a day.

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Santa Clara, California.— Jesuit Seismological Service, nos. 161-166, November 21, 1915, to June 27, 1916.

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Cartuja, Spain.—Boletin Mensual de la Estacion Seismologica de Cartuja, Granada, no. 3, March 1916.

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Stonyhurst College, England.— Earthquake Records of the Observatory, from April 5 to August 28, 1916.

PHILIPPINE ISLANDS

Manila, P. I.— Seismological Bulletin of the Observatory, nos. 5 to 19, from February 1 to June 21, 1916; also catalogue of Philippine earthquakes, 1915, a reprint from the Weather Bulletin for Dec. 1915.

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ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

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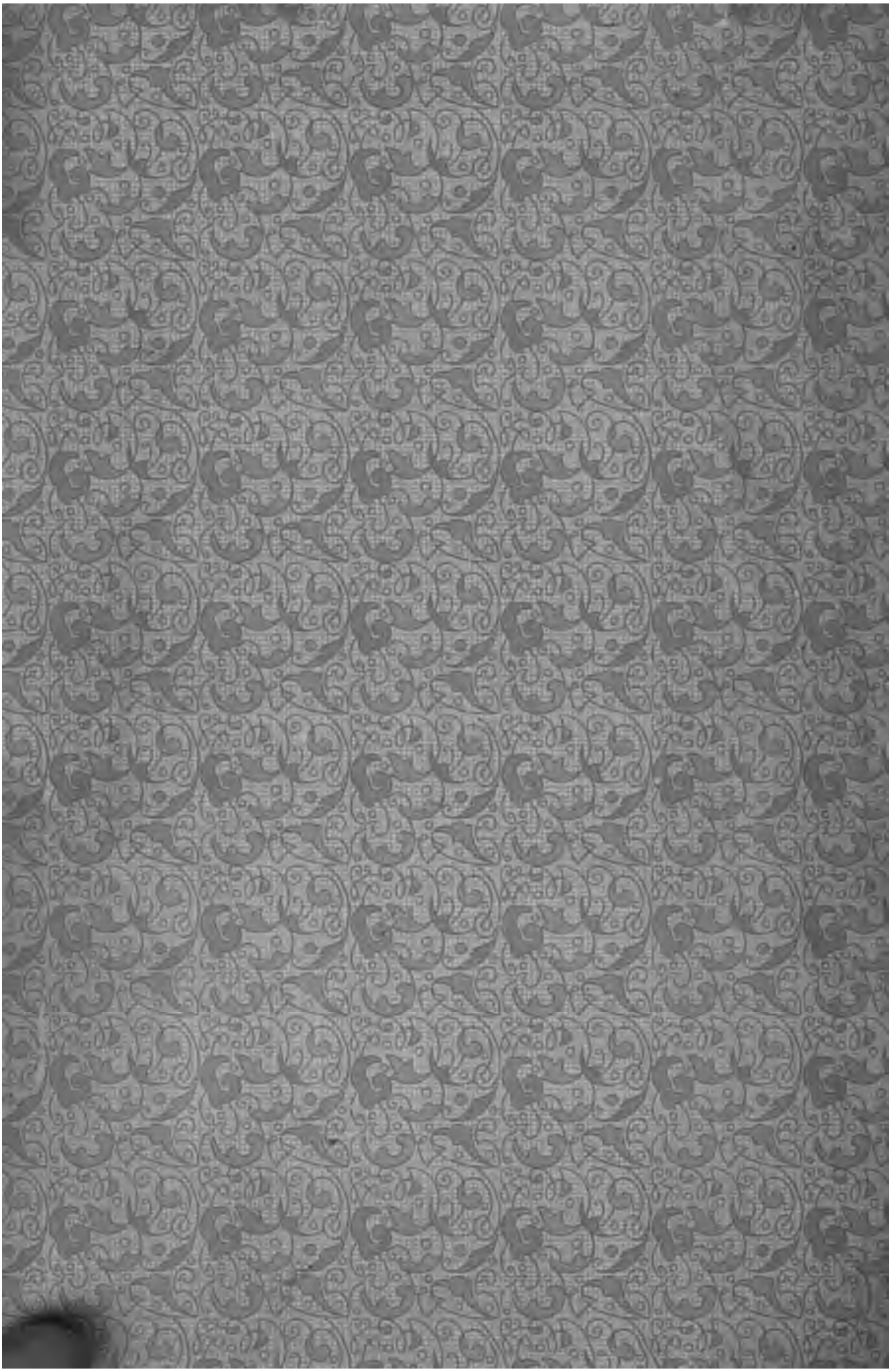

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